Environmental Research 108 (2008) 239–246

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Quantified activity pattern data from 6 to 27-month-old farmworker children for use in exposure assessment ☆

Paloma Beamer [a,*], Maya E. Key [b], Alesia C. Ferguson [c], Robert A. Canales [b], Willa Auyeung [b], James O. Leckie [b]

[a] Community, Environment and Policy, Mel and Enid Zuckerman College of Public Health, University of Arizona, AZ, USA
[b] Exposure Research Group, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA
[c] College of Public Health, University of Arkansas Medical Sciences, Little Rock, AR, USA

ARTICLE INFO

Article history:
Received 27 September 2007
Received in revised form
2 July 2008
Accepted 7 July 2008
Available online 23 August 2008

Keywords:
Mouthing behavior
Dermal exposure
Video translation
Pesticide exposure
Activity patterns
Non-dietary ingestion exposure

ABSTRACT

This study was conducted to describe exposure prone behaviors of infants and toddlers in the farmworker community. Analysis of hand and mouth contact frequencies and durations aids understanding of how children interact with their environment and are exposed via contact with surfaces. All 23 participating children (8 female infants, 5 male infants, 5 female toddlers and 5 male toddlers) lived with at least one farmworker. Children were videotaped at home for 2–6 h. Video footage was translated into micro-level activity time series (MLATS) for both hands and the mouth. MLATS were processed to calculate hourly duration in microenvironments, contact frequency, hourly contact duration and median contact duration. The median hourly duration spent indoors was 53 min/h. The median hand-to-mouth frequency was 15.2 events/h and the median object-to-mouth frequency was 27.2 events/h. The hourly mouthing duration was 1.2 and 2.2 min/h with the hands and objects, respectively. The median mouthing duration with hands and objects was 2 s. The median contact frequency for both hands combined was 689.4 events/h with an hourly contact duration of 100.5 min/h and a median contact duration of 3 s. Infants had higher mouthing frequencies with non-dietary objects while toddlers had higher mouthing frequencies with objects associated with pica (i.e., paper). Boys had higher contact frequencies while girls had longer contact durations. These sub-group differences indicate factors such as age and gender should be accounted for when conducting exposure assessments. Contact frequencies in this study are higher than current US EPA recommendations, questioning their protective value for infants and toddlers.

1. Introduction

The Food Quality Protection Act (FQPA, 1996) emphasizes the importance of determining children's aggregate exposure to pesticides through drinking water, diet, and residential-use pathways (Fenske et al., 2000). Farmworker children may have particularly high pesticide exposure due to additional residential contamination from agricultural aerosol drift and occupational take-home contamination on clothing, shoes or skin (Bradman et al., 1997).

Compared to adults, children are more susceptible to pesticide exposure due to their physiological characteristics and unique activity patterns. Physiologically, children have increased risk because of developing nervous and immune systems, low body weights, increased surface to body weight ratio, high metabolic rates, and high exertion levels (Cohen Hubal et al., 2000a; Moya et al., 2004; Zartarian et al., 1995). Children's activity patterns differ from adults in many ways. For example, children spend more time crawling and playing on the floor and have greater hand-to- and object-to-mouth contacts (Tulve et al., 2002). As children develop, their interaction with the environment changes, resulting in different activity patterns affecting the magnitude of their exposure (Cohen Hubal et al., 2000a). Infants learn about objects by mouthing (hand/object-to-mouth behaviors) (Moya et al., 2004). Mouthing behavior typically disappears around 18 months of age, but persists beyond this age for 10–30% of children (Baltrop, 1966; Lourie et al., 1963). Toddlers, because of their mobility, access a wider range of locations and objects (Moya et al., 2004). Characterizing children's mouthing behavior and

☆ *Funding Source*: This project was funded by Stanford's Dean Doctoral Diversity Fellowship, Stanford NIH Graduate Training Program in Biotechnology, EPA Star Grant (#RA2936201), CHAMACOS (EPA Grant #R826709 and NIEHS Grant #5P01 ES09605), and the UPS Foundation (#2DDA103). This research has not been subjected to federal peer and policy review.

* Corresponding author at: 1295 N. Martin Avenue, P.O. Box 245210, Tucson, Tucson, AZ 85724, USA. Fax: +1 520 626 8009.
E-mail address: pbeamer@email.arizona.edu (P. Beamer).

0013-9351/$ - see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2008.07.007

dermal contact as they develop from infants to toddlers is important in assessing their potential for dermal exposure and indirect ingestion of contaminants from objects, hands, and surfaces in their environment (Cohen Hubal et al., 2000a; Juberg et al., 2001; Tulve et al., 2002).

Direct observation (including videotaping) is considered the most accurate way to record a child's dermal contact and mouthing behaviors (Cohen Hubal et al., 2000a). In addition to eliminating recall bias, videotaping preserves real-time activities that can later be carefully analyzed for detailed contact frequency and duration, and for inter- and intra-observer reliability (Zartarian et al., 1997a). Essential information that can be extracted from videotape includes time spent in different microenvironments, the types of materials contacted, the rate of contact with surfaces, and the surface area of the contact (Moya et al., 2004). This approach may be the only viable approach for collecting activity patterns to estimate non-dietary ingestion since it allows quantification of frequent mouthing events of short duration (Cohen Hubal et al., 2000b; Juberg et al., 2001).

The current study was conducted to describe and compare exposure prone behavior of infants (6–13 months) and toddlers (20–27 months) in a farmworker community by performing an analysis of the contact events of their hands and mouths and of microenvironments visited. Videotaping methodologies and video-translation software (Virtual Timing Device™) developed at Stanford were utilized to record micro-level activity time series (MLATS) as computer text files that can be used to estimate exposure (Ferguson et al., 2005; Zartarian et al., 1997a). Approximately, 93 h (2–6 h per child) of videotape were obtained from 23 children during the summers of 2001 and 2002. While previous studies were performed to gather micro-activity data (Akland et al., 2000; AuYeung et al., 2004, 2006; Black et al., 2005; Brinkman et al., 1999; Freeman et al., 2001, 2005; Reed et al., 1999; Tulve et al., 2002; Zartarian et al., 1995, 1997a, b, 1998), analysis of duration in microenvironments, and frequencies and durations of contact events in this study will aid understanding of how children interact with their environment at different developmental stages (i.e., infants and toddlers). This study also expands available activity pattern data on farmworker children, who may be particularly vulnerable to pesticide exposure (Zartarian et al., 1995).

2. Methods

The original concept for this project was based on an earlier four-child pilot study in the farmworker community of Salinas, California (Zartarian et al., 1995). Many details pertinent to the scale-up of this effort were developed and refined during two subsequent projects with standardized protocols (Ferguson et al., 2005). Quality assurance and control were built into all aspects of the project and is a major feature of the operational protocols. The main project components are (1) solicitation of eligible farmworker families, (2) videotaping the children, (3) videotape translation into computer text files, and (4) quantification and analysis of children's contact behavior. All procedures were reviewed and approved by the Institutional Review Board at the University of California, Berkeley, and Stanford University.

2.1. Family solicitation and study population

A convenience sample of 23 children residing in the Salinas Valley was enrolled. Families were recruited through local community clinics, social service organizations, and word-of-mouth. Eligible participants were 6–13 months old (infants) or 20–26 months old (toddlers) and had at least one farmworker 18 years or older living in the same household resulting in eight female infants, five female toddlers, five male infants, and five male toddlers. The two age groups were selected to correspond with a longitudinal birth cohort study that evaluated the children at 6 and 24 months (Eskenazi et al., 2007). During the summer of 2002, pesticide and metabolite levels were measured in the homes and the children's urine (Bradman et al., 2007). However, all the researchers in the current activity pattern study were blinded to the results.

2.2. Videography

Two researchers videotaped each child's activities and kept a detailed written log of locations visited and objects and surfaces contacted by the child. A questionnaire was administered to acquire demographic data, housing and cleaning characteristics, eating patterns, and other pertinent information potentially affecting the child's pesticide exposure (Key M, in preparation). The questionnaire was administered orally in the language of choice (i.e., Spanish or English).

Each child was videotaped for a minimum of 4 h (with one exception where the child was videotaped for only 2 h because the mother had to leave). Videotaping began in the morning after breakfast and continued until the videographers collected 4 h of footage. The camera was turned off for diaper changes, breast-feeding, naps, and at the request of the caregiver. Thus, the researchers were in the house on average 5 h (range 2–8 h), or most of the daytime awake hours of the child.

The videographer tried to keep the child's whole body in view and stay as far from the child as possible to minimize the child's attentiveness to the videographer. Due to the size of the homes, it was often difficult to maintain an appropriate distance from the child and capture a full view of the body. Quality of videotaped footage was diminished at times due to poor indoor lighting. To clarify the characteristics of objects and surfaces, the videographer made voice annotations to complement the field notes. Due to fatigue from videotaping very active children for long periods, researchers took turns videotaping the child. The videographer effect was not accounted for during activity pattern analysis; however, both researchers underwent the same training.

2.3. Videotape translation

VTD is a Macintosh-based software tool designed to quantify real-time, sequential micro-level activity pattern data from videotapes (Zartarian et al., 1997a). The VTD computer interface (palette) is comprised three grids (Fig. 1). Each grid is composed of cells for either (a) microenvironments (locations), (b) activity function (e.g., repetitive or constant, moderate or high intensity), and (c) relevant objects/surfaces. While monitoring a contact boundary (e.g., right hand, left hand, mouth) on the videotape, a researcher records data by activating the appropriate cell in each grid. Grid activation initates a timer which records (to fractions of a second) the total duration of each contact event resulting in a series of contacts representing the entire video. For each body part, data can be collected simultaneously on microenvironments, activity function, surface/object contacted, and contact event duration.

The VTD palette used for this study is shown in Fig. 1. The microenvironment grid consists of 10 cells depicting typical locations where a child may play (e.g., yard, living room, etc.). The microenvironments were selected by grouping the different locations in the agricultural children's environment according to microenvironments that are likely to have similar chemical compositions in the air. For example, the living room, dining room, and hall were grouped together under the living room category. The kitchen, however, was a separate category due to different chemical use patterns. The contact type grid included "constant" and "repetitive" to account for repetitive actions such as crawling or bouncing a ball. The object grid contained 34 object/surface categories and categories designating when there is no contact with a surface ("nothing") and when the child's body part is not visible by the researcher ("not in view"). The object designations were selected based on experience from previous studies (AuYeung et al., 2004, 2006; Ferguson et al., 2005; Zartarian et al., 1997b, 1998). Nine "object purposes" were chosen (e.g., ground surfaces, walls/furniture, toys, etc.), and surface types were matched to the "object purposes" (e.g., rock/brick, wood, plastic). When the videotape was being translated for the hands, the palette was modified so that "mouth" replaced "hand" in the object grid (Fig. 1).

Three body parts were translated for this study (i.e., left hand, right hand, and the mouth). Previous micro-activity pattern studies (Ferguson et al., 2005) determined that although the feet have a higher contact frequency, bare hands have a greater contact frequency than bare feet. Thus, hands would most likely represent the body part with the greatest potential for dermal exposure. While the mouth has lower contact frequencies, it is essential for assessing non-dietary ingestion exposure.

Prior to translation, the video footage was divided into 30 min segments. It has been determined that this is the optimum time to reduce error and researcher fatigue (Ferguson et al., 2005). For the 23 children, there were 186 30 min segments resulting in a total of 93 h of footage. It took approximately 2 h to complete the three body part translations for a single segment, not including time spent rectifying errors. Close to 500 h was spent on video-translation.

To increase inter-observer reliability and accuracy, rigorous quality control measures were enacted for both translation training and the rest of the video-translation phase (Ferguson et al., 2005). Translators were required to memorize the palette before training. They then translated four practice tapes. Once their output files for each tape were in 90% agreement with "gold standard" files, they were allowed to commence translating videotapes collected from this study. The "gold standard" MLATS have been developed and tested by several translators

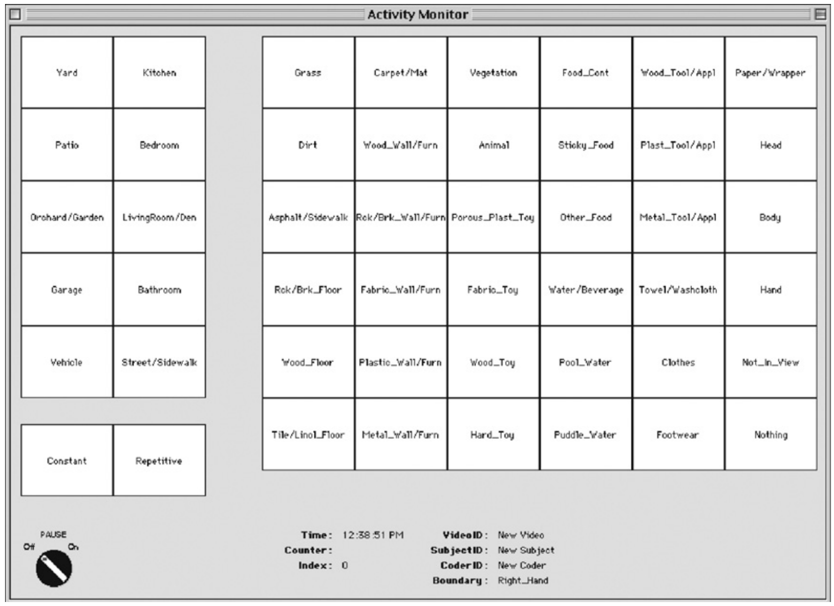

Fig. 1. VTD palette interface used for translation of the hands.

across five studies where we have used these methods (Ferguson et al., 2005). For the duration of the project, at least two segments from each child were tested for 90% agreement (for all three body parts) between the translator and a VTD expert. If 90% agreement was not achieved, the translator and the expert would go over the tape together to determine the discrepancy and the translator would then retranslate the segments for that child. In addition, several meetings were held during the course of video-translation with all translators to discuss assumptions on microenvironments and object designations.

To further ensure the accuracy and quality of the collected micro-activity patterns, each MLATS file was compared to the field notes taken at the time of videotaping (Beamer and Leckie, 2005). All contacts with objects or surfaces that were not recorded on the field notes were verified with the videotape footage. In some cases, the translator had accidentally activated the wrong cell in the object or location grid recording a false contact or microenvironment change. In other instances, the translator had misclassified the object (e.g., socks were misclassified as "footwear" instead of "clothes/towels"). All inaccurate contacts identified were corrected.

2.4. *Quantification and analysis of microenvironment and contact activity data*

Once all the videotape segments were translated and verified, the MLATS files were imported into S-PLUS 6.0, Intercooled STATA 9.0 and Microsoft Excel 2002 software for analysis. The files were processed in two ways before they were analyzed. First, repetitive contacts (from contact type grid) were assumed to alternate between contacts with the surface/object and air ("nothing") at the rate of two contacts per second. Second, continuous contacts occurring in different locations were joined to avoid double-counting contact frequencies (Ferguson et al., 2005).

Location categories from the VTD palette were grouped into indoors (bathroom, bedroom, kitchen, livingroom/den) and outdoors (garage, orchard/garden, patio, street/sidewalk, vehicle, yard). Object categories were grouped to form 16 object/surface super categories (Table 1). The following information was extracted: (1) hourly duration (min/h) in each microenvironment, (2) number of different objects contacted, (3) object contact frequency (events/h), (4) hourly contact duration (min/h), and (5) median duration of contact (in seconds). Descriptive statistics (i.e., median, range, and arithmetic mean) for all the children ($n = 23$) were calculated for each of these variables. Although the activity variables are not normally distributed, the arithmetic means were calculated to facilitate comparison with other studies.

Hourly duration was calculated by dividing the duration of time spent in each microenvironment or contacting an object by the total time the child was in view. Contact frequency was calculated by counting the number of contact events with a particular object/surface and dividing by the total time the child was in view. Median duration was computed for each child from all his/her contacts with each object/surface ($n = 1$–651). Super-categories were further grouped to perform analysis on non-dietary objects and all objects.

The above statistics calculated from the MLATS for the right and left hands for each child were compared using the Wilcoxon signed rank test to determine if each child demonstrated a dominant hand. No consistent trends (across all statistics) were found, and it was not possible to determine if there was hand dominance. Therefore, contacts for the left and right hand were grouped and are presented as "both hands" in the results.

Table 1
Super-category assignments for objects/surface

Super-categories	VTD object/surface palette categories
Animal	Animal
Body	Body, head
Clothes/towels	Clothes, towel/washcloth
Fabric	Fabric_wall/furn[iture]
Floor	Asphalt/sidewalk, carpet/mat, dirt, r[o]ck/br[ic]k_floor, tile/linol[eum]_floor, wood_floor
Food	Food_cont[ainer], other_food, sticky_food, water/beverage
Footwear	Footwear
Hands or mouth[a]	Hands, mouth
Metal	Metal_wall/furn[iture], metal_tool/appl[iance]
Non-dietary water	Pool_water, puddle_water
Paper/wrapper	Paper/wrapper
Plastic	Plastic_wall/furn[iture], plastic_tool/appl[iance]
Rock/brick	R[o]ck/br[ic]k_wall/furn[iture]
Toys	Fabric_toy, hard_toy, porous_plast[ic]_toy, wood_toy
Vegetation	grass, vegetation
Wood	Wood_tool/appl[iance], wood_wall/furn[iture]

[a] Depending upon the body part being translated.

The calculated variables above were grouped according to developmental stage (i.e., infants and toddlers) and gender. Since the data were not normally distributed, non-parametric tests were used to assess for statistical significance. Wilcoxon rank sum tests were conducted to determine if there were statistical differences in the time activity behavior between infants versus toddlers and between boys versus girls.

3. Results

3.1. *Time activity and micro-activity pattern summary*

Percent of the total time children were in view depended upon body part (median time in view: mouth = 96%, left hand = 91%, right hand = 90%). All 23 children spent the majority of their time in the indoor microenvironment (mean = 50.3, median = 53.1, and range = 33.5–60.0 min/h). The distribution of hourly duration spent in indoor and outdoor microenvironments is presented in Table S1 (see Supplementary material). No statistical differences in microenvironment hourly duration were found by developmental stage or gender.

Children contacted a large number of different objects with their mouths (mean = 13, median = 13, and range = 8–18 objects). They contacted an even larger number with their hands (mean = 24, median = 24, and range = 11–31). Summary statistics for object contact frequency (events/h) are presented in Table 2. Complete distributions are in Table S2 (see Supplementary material). The object with the highest mouthing frequency was food. The median mouthing frequency for non-dietary objects was 27.2 events/h, or a mouthing contact almost every other minute. Non-dietary objects with the highest mouthing frequency were hands and toys. For all objects/surfaces, the median hand contact frequency was 689.4 events/h or approximately 11 contacts per minute for both hands combined. Most frequently contacted objects by the hands were toys and clothes/towel. Other frequently contacted objects were body and plastic surfaces.

Summary statistics for object/surface hourly contact duration (min/h) are presented in Table 3. Complete distributions are in Table S3 (see Supplementary material). The object with the highest hourly mouthing duration was also food. The median hourly mouthing duration for non-dietary objects was 2.2 min/h. Non-dietary objects with the highest hourly mouthing duration were hands and toys. For all objects/surfaces, the median hourly contact duration was 100.5 min/h for both hands combined. Objects with the highest hourly contact duration were clothes/towel and food. Other objects with high hourly contact rates were plastic surfaces and toys.

Summary statistics for median contact duration (seconds) are presented in Table 4. Complete distributions are presented in Table S4. Only data from children who had contacted the object were included in the calculations. No children had mouth contacts with animals, non-dietary water or rock/brick surfaces while all children had mouth contacts with clothes/towel, food, hands, and toys. All children contacted body, clothes/towel, mouth, toys, and plastic surfaces with either hand. Median mouthing event durations for all children were very short ($\leqslant 10$ s) for most objects. For some objects (i.e., hands and toys), some children had longer mouthing durations. The median hand contact duration for all children is 3 s for both hands combined. For certain objects, hand contact durations for some children were much longer (i.e., food, footwear, paper/wrapper, and toys).

Table 2
Object/surface contact frequency (events/h) ($n = 23$)

Object/surface	Mouth			Both hands		
	Range	Mean	Median	Range	Mean	Median
Animal	–	–	–	0.0–4.3	0.2	0.0
Body	0.0–5.0	1.5	0.8	16.6–147.1	76.8	70.5
Clothes/towel	0.3–13.6	5.4	3.6	39.2–237.9	113.8	100.9
Fabric	0.0–5.7	1.1	0.3	0.0–134.4	45.6	37.6
Floor	0.0–1.3	0.2	0.0	0.0–594.5	96.0	41.5
Food	2.3–68.3	28.9	28.2	0.0–170.7	51.8	42.7
Footwear	0.0–8.9	0.7	0.0	0.0–47.0	7.8	2.4
Hands/mouth[a]	2.0–62.1	18.4	15.2	2.0–62.1	18.2	14.5
Metal	0.0–2.1	0.3	0.0	0.0–52.4	17.3	14.5
Non-dietary water	–	–	–	0.0–2.6	0.2	0.0
Paper/wrapper	0.0–13.6	2.1	0.8	0.0–75.3	18.1	18.7
Plastic	0.0–14.3	2.0	1.4	10.9–294.9	87.1	76.1
Rock/brick	–	–	–	0.0–17.4	3.4	1.6
Toys	0.3–48.4	14.7	12.5	28.3–300.4	121.2	98.8
Vegetation	0.0–18.2	0.8	0.0	0.0–16.3	3.8	0.3
Wood	0.0–3.9	0.5	0.0	0.0–65.4	24.9	27.2
Non-dietary objects	6.2–82.3	29.2	27.2	266.8–1180.0	600.8	568.7
All objects/surfaces	24.4–145.9	76.5	77.4	303.1–1206.0	686.3	689.4

[a] Mouth for contacts with both hands.

Table 3
Object/surface hourly contact duration (min/h) ($n = 23$)

Object/surface	Mouth			Both hands[a]		
	Range	Mean	Median	Range	Mean	Median
Animal	0.0–0.0	0.0	0.0	0.0–0.2	0.0	0.0
Body	0.0–0.3	0.1	0.0	1.6–21.9	7.5	5.9
Clothes/towel	0.0–0.9	0.3	0.2	4.5–31.0	13.1	12.4
Fabric	0.0–0.2	0.0	0.0	2.1–21.6	10.3	9.1
Floor	0.0–0.1	0.0	0.0	0.0–32.2	7.0	4.3
Food	0.3–15.0	4.7	3.8	0.0–37.1	14.2	12.1
Footwear	0.0–1.4	0.1	0.0	0.0–7.7	1.1	0.3
Hands/mouth[b]	0.2–5.4	1.4	1.2	0.1–7.4	1.8	1.5
Metal	0.0–0.2	0.0	0.0	0.0–5.2	2.0	1.9
Non-dietary water	0.0–0.0	0.0	0.0	0.0–0.0	0.0	0.0
Paper/wrapper	0.0–0.8	0.1	0.0	0.0–13.9	3.7	3.1
Plastic	0.0–0.6	0.1	0.1	0.9–50.6	13.5	10.9
Rock/brick	0.0–0.0	0.0	0.0	0.0–1.8	0.3	0.1
Toys	0.0–17.9	2.7	1.2	9.8–54.1	25.2	9.8
Vegetation	0.0–0.2	0.0	0.0	0.0–2.2	0.3	0.0
Wood	0.0–0.3	0.0	0.0	0.0–10.6	3.5	3.9
Non-dietary objects	0.3–18.4	3.5	2.2	62.6–106.2	83.1	83.2
All objects/surfaces	2.2–33.6	9.6	8.8	76.4–124.1	99.1	100.5

[a] Hourly contact duration for both hands is the sum of the hourly contact durations for the left and right hands independently.
[b] Mouth for contacts with both hands.

Table 4
Median object/surface contact duration (in seconds)[a]

Object/surface	Mouth				Both hands			
	n	Range	Mean	Median	n	Range	Mean	Median
Animal	0	–	–	–	2	1.5–2.0	1.8	1.8
Body	21	0–5.5	1.4	1.0	23	1.0–3.0	2.3	2.0
Clothes/towel	23	1.0–6.0	2.1	2.0	23	1.0–4.0	2.9	3.0
Fabric	14	1.0–5.0	2.1	2.0	22	2.0–9.0	3.6	3.0
Floor	8	0–3.0	1.2	1.0	21	0.5–5.0	2.3	2.5
Food	23	1.0–7.0	3.1	3.0	21	2.0–24.0	7.1	7.0
Footwear	4	1.5–8.0	4.8	4.8	21	1.0–11.0	3.8	3.0
Hands/mouth[b]	23	1.0–11.5	2.6	2.0	23	1.0–8.5	2.7	2.0
Metal	6	1.0–6.0	2.9	1.8	20	0.8–9.0	3.4	3.0
Non-dietary water	0	–	–	–	2	0.5–1.0	0.8	0.8
Paper/wrapper	19	0–5.0	2.1	2.0	21	1.5–11.5	4.4	4.0
Plastic	18	1.0–9.5	2.5	2.0	23	0.5–8.0	3.8	4.0
Rock/brick	0	–	–	–	17	1.0–5.0	2.7	3.0
Toys	23	1.0–83.0	7.0	3.0	23	3.0–11.5	5.8	5.0
Vegetation	1	0.5	0.5	0.5	14	0.5–4.0	2.7	3.0
Wood	8	0.5–10.0	3.1	2.0	20	1.5–8.0	3.8	3.0
Non-dietary objects	23	1.0–5.0	2.2	2.0	23	2.0–5.0	3.2	3.0
All objects/surfaces	23	1.0–5.0	2.4	2.0	23	2.0–5.0	3.3	3.0

[a] VTD rounds duration to the nearest half second.
[b] Mouth for contacts with both hands.

3.2. *Difference between infants and toddlers*

Several significant differences ($p<0.05$) were found between the micro-activity statistics for infants and toddlers. Toddlers contacted more types of objects (mean = 28, median = 28, range = 24–30) than infants (mean = 20, median = 20, range = 11–31) with p-value of 0.002. Distributions for objects with significant differences are presented for both infants and toddlers in Table S5. Infants had higher mouthing contact

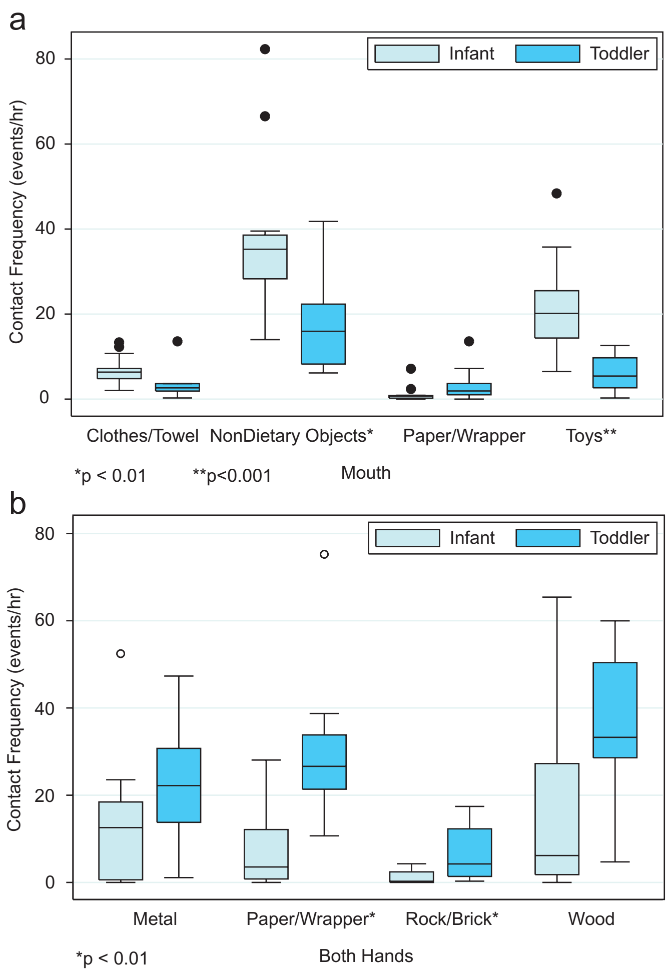

Fig. 2. Significant differences ($p<0.05$) between infants and toddlers in contact frequency (contacts/h) with the (a) mouth and (b) both hands.

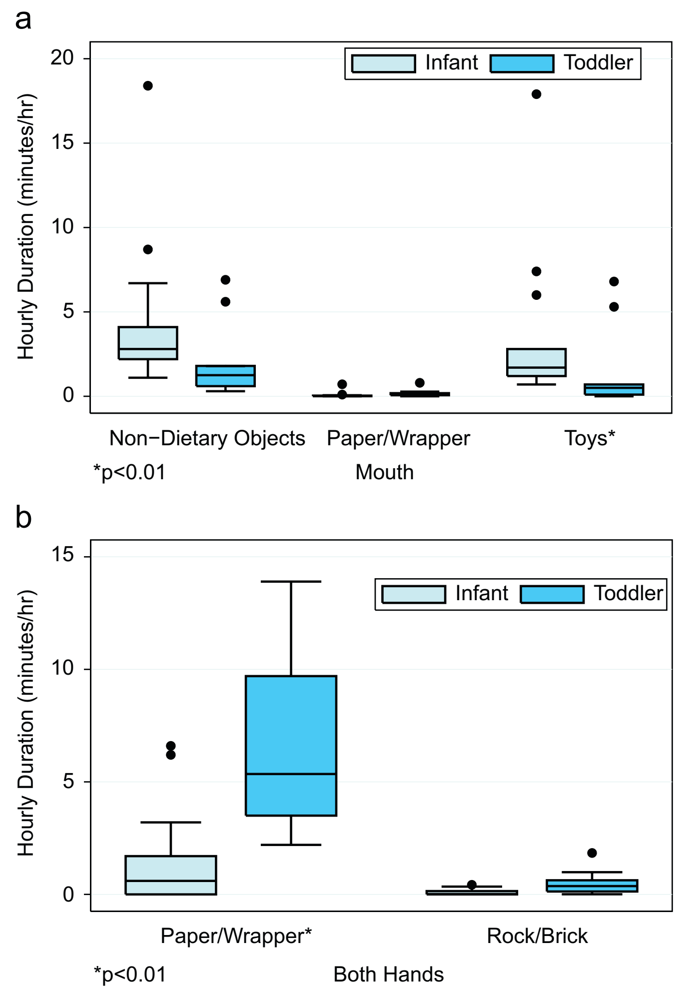

Fig. 3. Significant differences ($p<0.05$) between infants and toddlers in object/surface hourly contact duration (seconds) with (a) the mouth and (b) both hands.

frequencies with clothes/towels, toys, and all non-dietary objects (Fig. 2). Toddlers had higher mouthing frequencies with paper/wrapper and hand contact frequencies with paper/wrapper, metal, rock/brick, and wood surfaces. Similarly, infants had higher hourly mouthing duration with toys and all non-dietary objects and lower mouthing duration with paper/wrapper (Fig. 3). Toddlers also had higher hourly contact durations with paper/wrapper and rock/brick surfaces with both hands. Infants had shorter median hand contact durations with the floor (Fig. 4).

Infants had increased frequency and contact duration with objects most likely in their immediate environment and toddlers with objects and surfaces that require greater mobility to contact. Infants' increased mouthing of non-dietary objects compared to toddlers confirm results of several other studies that this behavior decreases with age (Black et al., 2005; Freeman et al., 2001; Juberg et al., 2001; Lourie et al., 1963; Tulve et al., 2002). Its persistence as a major activity past 18 months of age may be abnormal and result from pica (compulsive ingestion of a non-food substance). Among many objects, children with pica may ingest paper products (Lourie et al., 1963). This could explain why the toddlers in the current study had increased frequency and contact duration in their mouthing of paper/wrappers.

3.3. *Differences between boys and girls*

There were no statistical differences by gender in the number of unique objects contacted by the mouth or hands. Several

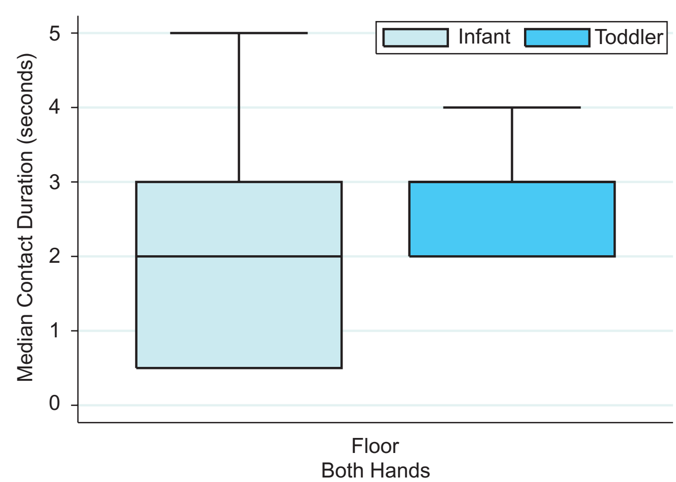

Fig. 4. Significant differences ($p<0.05$) between infants and toddlers in median contact duration (seconds) with both hands.

significant differences ($p<0.05$) were found between the micro-activity statistics for boys and girls. Distributions for objects with significant differences are presented for both boys and girls in Table S6. Boys had greater mouthing frequency with bodies (excluding hands) and hand contact frequency with the floor and

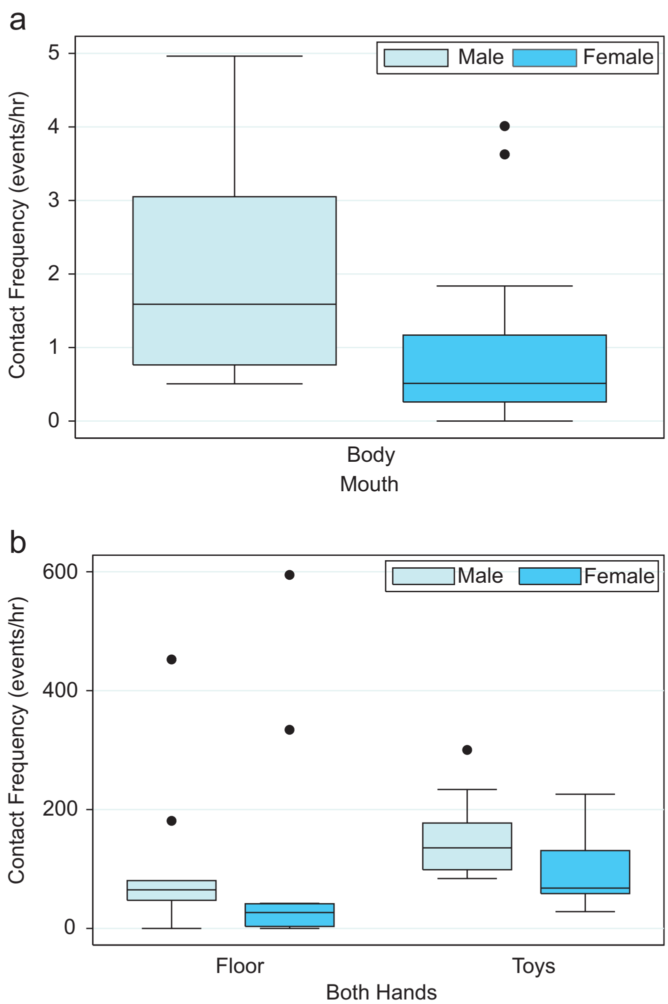

Fig. 5. Significant differences ($p<0.05$) between male and female children in contact frequency (events/h) with the (a) mouth and (b) both hands.

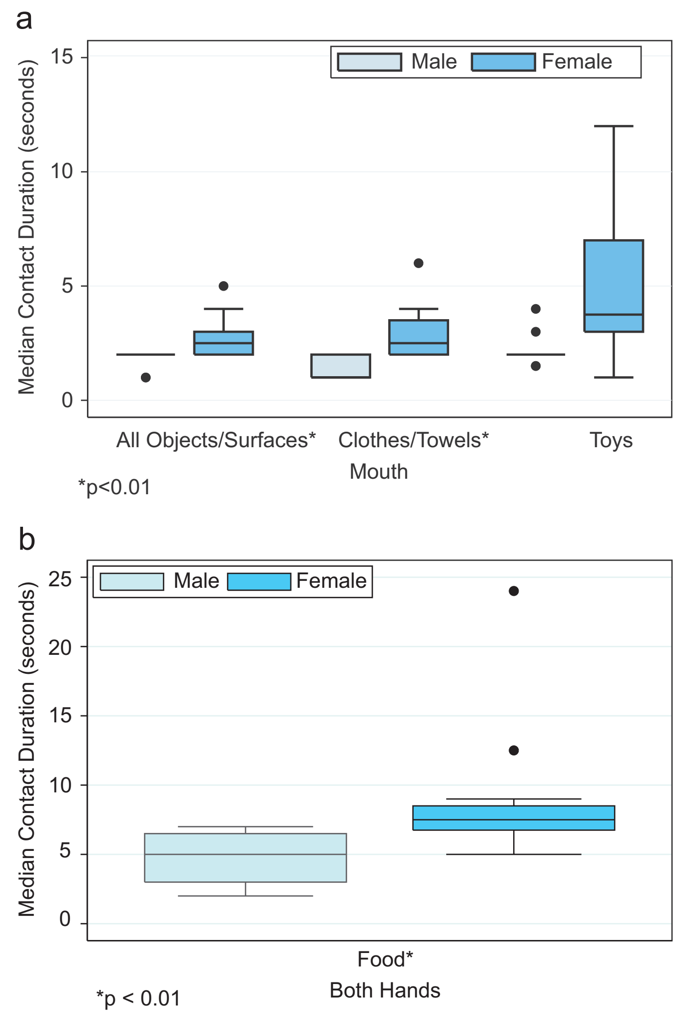

Fig. 6. Significant differences ($p<0.05$) between male and female children in median duration of contact (seconds) for the (a) mouth and (b) both hands.

toys (Fig. 5). Girls had longer median mouthing durations with clothes/towel, toys, and all objects/surfaces (Fig. 6). Girls had longer hand median contact durations with food. However, no significant differences were found between boys and girls for hourly contact duration. These results suggest that boys may have more frequent contacts with their environment while girls contact objects for longer durations. Understanding how frequency and duration contribute to dermal and non-dietary ingestion exposure could increase understanding of the potential difference in exposure between the genders.

4. Discussion

The current study confirms some observations from the pilot study (Zartarian et al., 1997b, 1998). For example, children's mouth and hand contacts exhibit short durations and high frequencies (Zartarian et al., 1997b). These observations verify the usefulness of videotaping as an activity data collection tool (Zartarian et al., 1998). In the current study, children spent about the same amount of time indoors as in the previous study. The children in the current study had much higher mouthing contact frequencies with hands and non-dietary objects. With the exception of contacts with hard floor, the children in the current study also had much higher hand contact frequency with objects and surfaces in their environments. This could be due to the children in the current study being much younger (6–27 months) than the children in the pilot study (2–4 years).

For three of the four children in the pilot study, the hourly duration for non-dietary objects in the mouth was less than one-fifth of the time that food and other diet-related items were placed in the mouth (Zartarian et al., 1998). For all 23 children in the current study, at least half of the total hourly mouthing duration was spent mouthing non-dietary objects. Of the 23 children, the median child spent 84% (range of 50.6–99.4%) of their hourly mouthing duration mouthing non-dietary objects. This may indicate that younger children spend more time mouthing non-dietary objects and confirms that non-dietary ingestion exposure may be a significant contributor to total ingestion exposure (Akland et al., 2000).

Due to differences in how activity pattern data were collected and analyzed, comparison with other studies is difficult. However, the trends observed in the comparison with the pilot study persist. For example, other studies confirmed that children do spend the majority of their time indoors while at home (Brinkman et al., 1999; Leech et al., 2002). Studies with children in the same age range (Black et al., 2005; Tulve et al., 2002) had much higher mouthing contact frequencies comparable with the current study than studies with older children (Freeman et al., 2005, 2001; AuYeung et al., 2004; Brinkman et al., 1999; Reed et al., 1999). Compared to other studies (AuYeung et al., 2006; Black et al., 2005; Freeman et al., 2005, 2001; Brinkman et al., 1999), the children in the current study had very high hand contact frequencies with food, carpet, and textured surfaces. They had comparable hand contact frequencies with toys and smooth surfaces and unusually low contact frequencies with hard floor.

Based upon previous studies, several recommendations have been made for estimating mouthing behavior. An early study on pica determined that a theoretical mouthing frequency 10 times a day of non-dietary items and hands as a reasonable estimate (Lepow et al., 1975). In the current study, we found this to be an underestimate, even on an hourly basis, where the median mouth contact frequency was 42.2 contacts per hour with hands and non-dietary objects. Work being done by US EPA (2001) to develop guidelines for calculating exposure to pesticides under several exposure scenarios originally suggested a value of 1.56 contacts/h as a hand-to-mouth frequency rate. After incorporating information from additional studies, the assumptions for hand-to-mouth activity were updated to an average of 9.5 events/h with the 90th percentile of 20 events/h based on data reported by Reed et al. (1999) (Tulve et al., 2002; US EPA, 2001, 2002). Meanwhile, the most recent Child-Specific Exposure Factor Handbook (US EPA, 2006) recommends an average total (hands and objects) mouthing contact frequency of 44, 54, and 20 contacts per hour for children aged 6 to <12 months, 12 to <24 months, and 24 to <36 months, respectively. In the current study for the same age groups, average mouthing contact frequency is 54, 55, and 24 contacts per hour. While the values are similar to the recommendations, 64% of the children aged 6 to <12 months and 67% of the children aged 24 to <36 months exceeded this value, confirming that the recommendation might not be protective for young children.

Although five researchers participated in video-translation, the translator effect was not accounted for in the analyses. One translator completed approximately 43% of the total translation; however, her translations are evenly distributed amongst all of the subgroups (i.e., males, females, toddler, and infants). A different researcher translated a disproportionate number of the male and toddler children. While this may have added some bias to the analyses, the results indicate that male children have greater frequencies of contact, while toddlers had lower frequencies of contact. Thus, translator biases are probably small compared to child activity differences by sub-group.

Our study found that infants had higher mouthing frequencies and hourly mouthing duration than toddlers except with objects associated with pica. Toddlers had higher frequency and hourly contact duration of hand contacts with objects that required mobility to reach. Boys had higher contact frequency while girls had longer contact durations. This study adds to the current database on children's micro-activity patterns used to assess exposure by focusing on a particularly vulnerable group, farmworker children. In the future, MLATS from this study will be combined with concurrent environmental measurements to construct sequential time exposure profiles and validate an aggregate exposure model. Exposure-prone behaviors can be identified and should aid the development of intervention strategies for this sensitive population.

Acknowledgments

The authors would like to thank the families for their participation in the study. They would also like to acknowledge the contribution of various researchers including Sonia Lopez, Sonrisa Lucero, Enrique Carballo, Viviana Acevedo-Bolton, Young Chun, Amy Hui, Cristina Correa, Ajamu Kitwana, and Nolan Cabrera. We appreciate the contributions of Asa Bradman and Brenda Eskenazi, and the rest of the CHAMACOS staff.

Human subjects: A human subjects protocol (titled "Time Activity Analysis of Children's Dermal Contact Behavior in the Salinas Valley, California") and bilingual informed consent form were approved by the Institutional Review Boards at both the University of California, Berkeley (Protocol #2001-2-22, approved 10 May 2001) and Stanford University (Protocol #0001-332, approved 29 June 2001).

Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2008.07.007.

References

Akland, G.G., Pellizzari, E.D., Hu, Y., Roberds, M., Rohrer, C.A., Leckie, J.O., Berry, M.R., 2000. Factors influencing total dietary exposures of young children. J. Expo. Anal. Environ. Epidemiol. 10, 710–722.

AuYeung, W., Canales, R.A., Beamer, P., Ferguson, A.C., Leckie, J.O., 2004. Young children's mouthing behavior: an observational study via videotaping in a primarily outdoor residential setting. J. Child. Health 2 (3–4), 271–295.

AuYeung, W., Canales, R.A., Beamer, P., Ferguson, A.C., Leckie, J.O., 2006. Young children's hand contact activities: an observational study via videotaping in primarily outdoor residential settings. J. Expo. Sci. Environ. Epidemiol. 16, 434–446.

Baltrop, D., 1966. The prevalence of pica. Am. J. Dis. Child. 112, 116–123.

Beamer, P., Leckie, J.O., 2005. Systematic verification of micro-level activity time series data to reduce uncertainty. In: Proceedings of the Conference the International Society of Exposure Analysis, 30 October–4 November 2005, Tucson, AZ, USA.

Black, K., Shalat, S.L., Freeman, N.C.G., Jimenez, M., Donnelly, K.C., Calvin, J.A., 2005. Children's mouthing and food-handling behavior in an agricultural community on the US/Mexico border. J. Expo. Anal. Environ. Epidemiol. 15, 244–251.

Bradman, M.A., Harnly, M.E., Draper, W., Seidel, S., Teran, S., Wakeham, D., Neutra, R., 1997. Pesticide exposures to children from California's Central Valley: results of a pilot study. J. Expo. Anal. Environ. Epidemiol. 7, 217–234.

Bradman, A., Whitaker, D., Quirós, L., Castorina, R., Claus Henn, B., Nishioka, M., Morgan, J., Barr, D.B., Harnly, M., Brisbin, J.A., Sheldon, L.S., McKone, T.E., Eskenazi, B., 2007. Pesticides and their metabolites in the homes and urine of farmworker children living in the Salinas Valley, CA. J. Expo. Sci. Environ. Epidemiol. 17 (4), 331–349.

Brinkman, S., Gialamas, A., Jones, L., Edwards, P., Maynard, E., 1999. Child activity patterns foe environmental exposure assessment in the home. National Environmental Health Monographs, Exposure Series No. 1. Australia.

Cohen Hubal, E.A., Sheldon, L.S., Burke, J.M., McCurdy, T.R., Berry, M.R., Rigas, M.L., Zartarian, V.G., Freeman, N.C.G., 2000a. Children's exposure assessment: a review of factors influencing children's exposure, and the data available to characterize and assess that exposure. Environ. Health Perspect. 108 (6), 475–486.

Cohen Hubal, E.A., Sheldon, L.S., Zufall, M.J., Burke, J.M., Thomas, K.W., 2000b. The challenge of assessing children's residential exposure to pesticides. J. Expo. Anal. Environ. Epidemiol. 10, 638–649.

Eskenazi, B., Marks, A.R., Bradman, A., Harley, K., Barr, D.B., Johnson, C., Morga, N., Jewell, N.P., 2007. Organophosphate pesticide exposure and neurodevelopment in young Mexican–American children. Environ. Health Perspect. 115, 792–798.

Fenske, R.A., Lu, C., Simcox, N.J., Lowewenherz, C., Touchstone, J., Moate, T.F., Allen, E.H., Kissel, J.C., 2000. Strategies for assessing children's organophosphorus pesticide exposures in agricultural communities. J. Expo. Anal. Environ. Epidemiol. 10, 662–671.

Ferguson, A.C., Canales, R.A., Beamer, P., AuYeung, W., Key, M., Munninghoff, A., Lee, K.T., Robertson, A., Leckie, J.O., 2005. Video methods in the quantification of children's exposures. J. Expo. Anal. Environ. Epidemiol. 16, 287–298.

Food Quality Protection Act (FQPA) of 1996, 1996. Public Law, pp. 104–170.

Freeman, N.C.G., Jimenez, M., Reed, K.J., Gurunathan, S., Edwards, R.D., Roy, A., Adgate, J.L., Pellizzari, E.D., Quackenboss, J., Sexton, K., Lioy, P.J., 2001. Quantitative analysis of children's microactivity patterns: The Minnesota Children's Pesticide Exposure Study. J. Expo. Anal. Environ. Epidemiol. 11, 501–599.

Freeman, N.C.G., Hore, P., Black, K., Jimenez, M., Sheldon, L., Tulve, N., Lioy, P.J., 2005. Contributions of children's activities to pesticide hand loadings following residential pesticide application. J. Expo. Anal. Environ. Epidemiol. 15, 81–88.

Juberg, D.R., Alfano, K., Coughlin, R.J., Thompson, K.M., 2001. An observational study of object mouthing behavior by young children. Pediatrics 107, 135–142.

Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S., Raizenne, M.E., 2002. It's about time: a comparison of Canadian and American time-activity patterns. J. Expo. Anal. Environ. Epidemiol. 12, 427–432.

Lepow, M.L., Bruckman, L., Gillette, M., Markowitz, S., Robino, T., Kapish, J., 1975. Investigations into sources of lead in the environment of urban children. Environ. Res. 10, 415–426.
Lourie, R.S., Layman, E.M., Millican, F.K., 1963. Why children eat things that are not food. Children 10, 143–146.
Moya, J., Bearer, C.F., Etzel, R.A., 2004. Children's behavior and physiology and how it affects exposure to environmental contaminants. Pediatrics 113, 996–1006.
Reed, K.J., Jimenez, M., Freeman, N.C.G., Lioy, P.J., 1999. Quantification of children's hand and mouthing activities through a videotaping methodology. J. Expo. Anal. Environ. Epidemiol. 9, 513–520.
Tulve, N.S., Suggs, J.C., McCurdy, T., Cohen Hubal, E.A., Moya, J., 2002. Frequency of mouthing behavior in young children. J. Expo. Anal. Environ. Epidemiol. 12, 259–264.
US EPA, 2001. Update to the Residential SOPs Dated February 22, 2001. (Policy 12). US Environmental Protection Agency, Washington, DC.
US EPA, 2002. Child-Specific Exposure Factors Handbook. EPA/600/P-00/002B. US Environmental Protection Agency, Washington, DC.
US EPA, 2006. Child-Specific Exposure Factors Handbook 2006 (External Review Draft). EPA/600/R-06/096A. US Environmental Protection Agency, Washington, DC.
Zartarian, V.G., Streicker, J., Rivera, A., Cornejo, C.S., Molina, S., Valadez, O.F., Leckie, J.O., 1995. A pilot study to collect micro-activity data of two to four-year-old farm labor children in Salinas Valley, California. J. Expo. Anal. Environ. Epidemiol. 5, 21–34.
Zartarian, V.G., Ferguson, A.C., Ong, C.G., Leckie, J.O., 1997a. Quantifying videotaped activity patterns: video translation software and training methodologies. J. Expo. Anal. Environ. Epidemiol. 7, 535–542.
Zartarian, V.G., Ferguson, A.C., Leckie, J.O., 1997b. Quantified dermal activity data from a four-child pilot field study. J. Expo. Anal. Environ. Epidemiol. 7, 543–552.
Zartarian, V.G., Ferguson, A.C., Leckie, J.O., 1998. Quantified mouthing activity data from a four-child pilot field study. J. Expo. Anal. Environ. Epidemiol. 8, 543–553.