Science of the Total Environment 627 (2018) 844–851

Contents lists available at ScienceDirect

Science of the Total Environment

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

Determination of hand soil loading, soil transfer, and particle size variations after hand-pressing and hand-mouthing activities

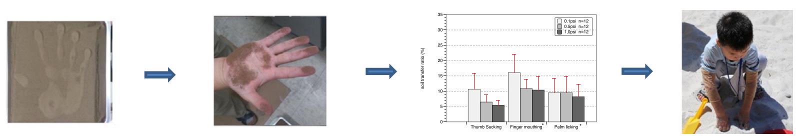
Hsing-Cheng Hsi [a], Ching-Yao Hu [b], Ming-Chien Tsou [b], Han-Jung Hu [a], Halûk Özkaynak [c,1], Karen Bradham [c], Zeng-Yei Hseu [d], Winston Dang [b], Ling-Chu Chien [b,*]

[a] Graduate Institute of Environmental Engineering, National Taiwan University, 71 Chou-Shan Road, Taipei 106, Taiwan
[b] School of Public Health, Taipei Medical University, 250 Wu-Hsing Street, Taipei 11031, Taiwan
[c] National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency (D205-05), Research Triangle Park, NC 27711, USA
[d] Department of Agricultural Chemistry, National Taiwan University, 1 Roosevelt Road, Sec. 4, Taipei 106, Taiwan

HIGHLIGHTS

- Factors influencing hand soil loading and hand-to-mouth transfer were examined.
- Sand causes higher soil loadings on hand than clay.
- Most particles sizes of transferred soil adhered to hand are <150 μm.
- Soil loading and transfer ratio are important factors for health risk assessment.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 December 2017
Received in revised form 28 January 2018
Accepted 29 January 2018
Available online xxxx

Editor: Adrian Covaci

Keywords:
Soil loading
Mouthing activity
Soil transfer
Soil texture
Exposure
Health risk

ABSTRACT

Hand-pressing trials and hand-to-mouth soil transfer experiments were conducted to better understand soil loadings, soil transfer ratios for three mouthing activities, and variations in particle size distributions under various conditions. Results indicated that sand caused higher soil loadings on the hand than clay. When the moisture level of clay soil exceeded its liquid limit, soil loadings also increased. Greater pressing pressures also led to larger clay loadings. Clay with a moisture content close to its plastic limit caused the smallest soil loadings due to strong soil cohesion. Particle sizes of the transferred clay were larger than that of the original clay, indicating that hand-pressing and the pressure exerted may have enhanced clay particles of larger sizes adhering onto the hand. Nevertheless, the sizes of most particles that adhered to the hand were still smaller than 150 μm. Higher pressing pressures and greater moisture contents resulted in larger soil loadings on the hand, and transfer ratios became smaller. Transfer ratios from palm-licking with clay particles were smaller than those from finger-mouthing, which may have been due to finer particles that more readily adhered to the skin of the palm and that were transferred from the hand to the mouth with greater difficulty.

1. Introduction

A human health risk assessment is the process of estimating the nature and likelihood of adverse health effects in humans resulting from present or anticipated exposures to chemicals in contaminated environmental media (USEPA, 2004). An assessment of exposures to chemicals from contaminated soil via ingestion and dermal contact pathways requires that information be gathered on soil adherence to the skin and hand-to-mouth transfer. These parameters are then used to determine the magnitude of the exposure risk, along with data on the content and speciation of contaminants found in the soil through a chemical analysis.

* Corresponding author.
E-mail address: lcchien@tmu.edu.tw (L.-C. Chien).
[1] Retired.

https://doi.org/10.1016/j.scitotenv.2018.01.308

Children may experience higher exposure risks through soil ingestion and dermal contact than adults, because children exhibit higher frequencies and durations of mouthing behaviors, especially early in their lives. Children also spend more time playing outside on the ground than do adults. Moreover, toxic substances in the soil may pose higher risks to children, because children are more susceptible than adults leading to increased contact with soil and sands. In a US Environmental Protection Agency (EPA) report, children within the age group of 3 to <6 years old were identified as being of great concern, because of relevant types of exposure behaviors that occur in this age range. In particular, children in this age group exhibit high hand-to-mouth activities, which contribute to elevated soil and dust ingestion rates and exposure to contaminants in the soil and dust (USEPA, 2005). Children older than 6 years begin wearing adult-style clothing, which may reduce the available body area for dermal contact, and also their hand-to-mouth activities become less frequent. It was shown that oral contact with the hands and objects, as well as their dermal contact with surfaces decrease for children who are 6 to <11 years old (USEPA, 2005).

Variations in soil ingestion intake due to mouthing behaviors of children depend on the amount of adherence of soil to the skin and the amounts of soil transferred from the object contacted to the skin and mouth. These variables are highly correlated with the size of soil particles and moisture content of the soil (Bergstrom et al., 2011; Choate et al., 2006a; Choate et al., 2006b; Ferguson et al., 2009a; Kissel et al., 1996a; Kissel et al., 1996b; Vasiluk et al., 2011). Sheppard and Evenden (1994) found that soils with particle sizes of <50 μm in diameter preferentially adhered to the skin; the concentrations of soil-bound contaminants, such as lead, mercury, uranium, and hexachlorobenzene, were up to 10-fold greater in the fine adhering fraction of the soil compared to those in bulk soils. Luo et al. (2011) also noted that concentrations of trace metals tended to be greater in the fine fractions of soil than in bulk soils. Moreover, these trace metals were found to mainly accumulate in clay and fine silt.

The contact pressure and duration are also among factors that can influence soil adherence values. Ferguson et al. (2009b) indicated that soil transfer increased as the contact pressure increased, but when the contact durations exceeded 30 s, adherence values did not seem to further increase. Other studies showed that greater test pressures and longer contact durations caused greater soil adherence (Ferguson et al., 2009a, 2009b).

Thus, a better understanding of particle size distributions prior to and after soil transfer from objects to the skin and from skin to the mouth is as important as knowing subsequent amounts of soil transfer for assessing exposures and chemical risks resulting from contacting contaminated soils. Earlier laboratory experiments in which adult subjects pressed their hands onto soil were mainly designed to measure soil adherence values. Results from those studies showed that finer soil particles adhered more efficiently to hands than did coarse soil samples (Ferguson et al., 2009a; Yamamoto et al., 2006). However, available studies pertaining to understanding hand-to-mouth transfer of soils are still limited. The only identifiable study was conducted by Kissel et al. (1998a), in which a laboratory-based examination was performed. The soil tested was a sub-2-mm fraction of natural loamy sand, which was first autoclaved and stored at room temperature under foil. Moisture contents in that experiment ranged 0.8%~1.6%. The experimental results also showed that palm-licking caused the largest amount of hand-to-mouth transfer of soil, followed by finger-mouthing and thumb-sucking (Kissel et al., 1998a).

In this study, hand-pressing trials and hand-to-mouth soil transfer experiments were carried out in an attempt to better understand soil loading on the hands and the tendency of particle size variations during soil-to-hand and hand-to-mouth transfer. We also investigated the dependence of soil transfer, soil loading, and hand-to-mouth transfer ratios during three types of mouthing activities and variations in the particle size distribution due to several parameters, including the soil texture, moisture content, contact time, and pressing pressure.

Recent studies conducted in Taiwan, similar to research reported by Kissel et al. (1998a), were previously undertaken in order to enhance our earlier children behavioral studies pertaining to mouthing activities and soil-ingestion rates of children (Chien et al., 2017; Tsou et al., 2015). In the current study, we aimed to enhance and strengthen the local database established for assessing exposures and health risks of children living near contaminated sites. This area of research has been a key area of concern of the Taiwan Environmental Protection Agency (TEPA, 2010).

2. Experimental

2.1. Test parameters for soil-transfer studies and hand-to-mouth transfers

Hand-pressing trials and hand-to-mouth soil transfer experiments were conducted with a total of four (two male and two female) adult volunteers with varying hand surface areas (Table S1), to reflect incidental soil ingestion pathways of children. This study was reviewed and approved by the Taipei Medical University-Joint Institutional Review Board (approval no: 201101026). All four volunteers signed a consent form. The hand-pressing trials were conducted to determine amounts of soil transferred to the hand. In contrast, the hand-to-mouth transfer ratio was expressed as the mass fraction of the total hand load transferred to the mouth by three types of mouthing activities. Key factors that could influence hand soil loading and the hand-to-mouth transfer ratio were examined as follows.

(1) Soil texture: Soils with two textures were selected, including sand (i.e., 0.05–2.0 mm) and clay (i.e., ≤0.002 mm). In addition, standard soils (Nacalai Tesque, Inc., Kyoto, Japan) were commercially obtained and tested.
(2) Contact pressure: Three contact pressures of 0.1, 0.5, and 1.0 psi, were tested, following Hubal et al. (2008).
(3) Contact time: The contact time for the soil-to-hand press tests was set to 3 s based on Beamer et al. (2008), and the hand-to-mouth contact time was set to 1 s based on our previous study (Tsou et al., 2017).
(4) Standard sand and clay was selected to examine the dependence of soil loading and hand-to-mouth transfer on the moisture content of the soil. The moisture content was 0.1% of the original standard sand. On the basis of Das (2009), which showed that the liquid limit (LL) of a typical clay sample was 50.0% and the plastic limit (PL) was 30.9%, four moisture contents were applied to the soil including 10% (i.e., the moisture content of the original standard clay), 30%, 50%, and 60%. The moisture content was calculated by the following equation:

$$\theta_w = W_w / W_s \quad (1)$$

where θ_w is the unitless weight ratio of water to soil, W_w is the water weight, and W_s is soil weight.

2.2. Hand-pressing trails

Hand soil loadings from hand-pressing trials were determined based on methods described by Kissel et al. (1998a). The main steps of this protocol included:

(1) Washing a subject's hands thoroughly, then air-drying with a blower for 20 s.
(2) Hand pressing (with the palm down and fingers spread) onto a shallow pan containing autoclave-sterilized soil for 3 s with pressing pressures of 0.1, 0.5, and 1.0 psi.
(3) Washing the soils from both hands and collecting the wash water in a plastic bottle.