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Soil-to-skin adherence during different activities for children in Taiwan

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ABSTRACT

Children may be exposed to environmental contaminants through incidental ingestion of soil resulting from hand-to-mouth contact. We measured soil adherence to the skin among 86 children from four kindergartens and one elementary school in Taiwan. Rinse water samples were collected from the hands, forearms, feet and lower legs of children after they had engaged in assigned activity groups (pre-activity, indirect contact and direct contact) from two different soil textures groups: sand and clay. We found that the soil loadings significantly differed between the different soil textures, body parts, activities, and clothing groups. Measured soil loadings for hands of pre-activity, indirect contact activity, and direct contact activity groups were 0.0069, 0.0307 and 0.153 mg cm^{-2}, respectively, for the group playing on sand and 0.0061, 0.0116 and 0.0942 mg cm^{-2}, respectively, for the group playing on clay. To facilitate the use of soil adherence data in exposure assessments, we provided a new and simple way to group activities based on the intensity of children's interactions with soil. The adherence data from this study can help enhance existing information based on soil-to-skin adherence factors used to assess children's exposure to soil contaminants during their play activities.

1. Introduction

Children are exposed to soil during their play activities and exhibit unique activity patterns, such as frequent hand and mouth contact behaviors with objects/surfaces (AuYeung et al., 2004, 2006; Beamer et al., 2008, 2012; Black et al., 2005; Reed et al., 1999; Tsou et al., 2015; Tulve et al., 2002; Zartarian et al., 1995, 1997a, 1997b, 1998). Metals from various natural and anthropogenic sources can accumulate in soil (Khan et al., 2008; Zhang et al., 2010). Thus, metals in soil may enter into the bodies of children through ingestion of soil that has adhered to their skin on their hands and bodies. In addition, children can be exposed to other contaminants, such as polycyclic aromatic hydrocarbons (PAHs) (Kadi et al., 2018; Peng et al., 2011; Tarafdar and Sinha, 2018; Wang et al., 2011; Yu et al., 2014; Zhou and Lu, 2017) and phthalates (Bekö et al., 2013; Bu et al., 2018; Kadi et al., 2018), in soils and/or dusts via dermal exposure. Recent studies used soil adherence factors to estimate soil ingestion rates for children (Özkaynak et al., 2011; Wilson et al., 2013).

There have been studies that investigated factors which may affect soil adherence in laboratory settings (Bergstrom et al., 2011; Ferguson et al., 2009a, 2009b; Kissel et al., 1996a; Yamamoto et al., 2006). In general, wet soils (Bergstrom et al., 2011; Kissel et al., 1996a) and play sands (Ferguson et al., 2009a, 2009b) had higher soil loadings than dry soils and lawn soils, respectively. Finer soil particles appeared to adhere to a greater extent to the hands (Ferguson et al., 2009a, 2009b; Kissel et al., 1996a; Yamamoto et al., 2006). Some of those studies simulated contact using a mechanical methodology rather than subjects to obtain a larger experiment setting (n of experiments = 379–748) (Ferguson et al., 2009a, 2009b). Other studies conducted in laboratory settings used adult volunteers to determine soil adherence under different affecting factors. However, the number of subjects was usually too small (n of subjects = 1–6) in laboratory experiments (Bergstrom et al., 2011; Kissel et al., 1996a; Yamamoto et al., 2006). Even though it is possible to control the main factors that may affect soil adherence to skin in laboratory experiments, it is difficult to simulate real-world conditions involving serial contact events or typical activities of children in a laboratory. In contrast, a well-designed field study can provide realistic estimates of soil adherence to different body parts following different

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types of activities by children contacting soils. However, to date there have been few field studies that investigated soil-to-skin adherence factors (Holmes et al., 1999; Kissel et al., 1996b; Shoaf et al., 2005; Yamamoto et al., 2006). Previous studies indicated that soil loadings varied by body part and, in general, were higher for hands and feet than for forearms and lower legs (Holmes et al., 1999; Kissel et al., 1996b; Shoaf et al., 2005). Studies also reported that soil loadings for hands were dependent on the types of activity performed (Holmes et al., 1999; Kissel et al., 1996b). In addition, Yamamoto et al. (2006) reported that the mass and size distribution of soils that adhered to hands of children largely varied with the play patterns, even though the children played in the same area. In general, the number of children studied was small in the same or similar activity that was assigned in the published studies for soil adherence for children (Holmes et al., 1999; Kissel et al., 1996b; Shoaf et al., 2005; Yamamoto et al., 2006). Moreover, it is worth noting that there was only a single study conducted in Asia (Japan) (Yamamoto et al., 2006). We speculated that the activities of children who engage in outdoor play, as well as soil textures and environments which children access, may differ between the children living in the United States (U.S.) and those in Asia. Thus, it is important to more comprehensively study differences in soil adherence rates between US children and Taiwanese/Asian children.

The principal objective of this study was to investigate the soil-to-skin adherence for children aged 4 to < 9 years living in Taiwan after they had engaged in different levels of outdoor activities on different types of soil textures, i.e., sand or clay, which they can typically access. We estimated the soil adherence values for the hands, forearms, feet and lower legs. In addition, play activities were grouped based on the intensity of interaction with soil, i.e., pre-activity, indirect contact, and direct contact groups, in order to estimate whether soil adherence values increased as a function of an increase in the amount of contact with soils. We also investigated the effect of age, gender and clothing on estimated soil-to-skin adherence values.

2. Methods

This study was reviewed and approved by the Taipei Medical University - Joint Institutional Review Board (approval no: 201101026).

2.1. Subjects and locations

In total, 86 children were recruited from four kindergartens (one in Taipei, one in Hualien, and two in Hsinchu) and one elementary school in Hualien, Taiwan during June to October 2013, and August to September 2014. We classified children into two groups according to the soil texture type that these children could access: sand and clay. Summary descriptions of the number of children and activity observations, activities, and clothing for the sand and clay groups are respectively presented in Table S1 and S2 in the Supporting information. The sand group included children in the kindergarten and the elementary school in Hualien as well as children who played in a sandbox in a kindergarten in Taipei. The clay group included children in the kindergartens in Hsinchu and children who played on the playground (outside of the sandbox) in kindergarten in Taipei. Children were sampled after they had finished a given assigned activity. All assigned activities were conducted outdoors. We categorized the activities into 3 groups: pre-activity, indirect contact, and direct contact. Pre-activity was defined as the period when children just had arrived at the school and had not yet engaged in any outdoor activity. Indirect contact was defined as an activity which did not involve contacting soil deliberately, i.e., playing with a ball or on a play set. Direct contact was defined as an activity which resulted in deliberate contact with soil, i.e. playing with sand in the sand box or with soil on the bare ground. We also investigated the effect of shoes on soil adherence for the feet and the effect of pants on soil adherence for the lower legs. The types of shoes were categorized into 3 groups: shoes with socks, shoes without socks and barefoot. The types of pants were categorized into 2 groups: long pants and short pants, skirt, or cropped pants. Cropped pants were defined as pants that ended anywhere from below the knee to above the ankle.

2.2. Rinse washing samples

Rinse washing samples were collected from four body parts (the hands, forearms, feet and lower legs) after the children had finished an assigned activity. Soil particles that had adhered onto the body parts were collected in the following order: hands, forearms, feet and lower legs. The rinse washing sample collection procedures are shown in Fig. S1. Children put the assigned body part above a funnel which was connected to a sample jar. A sprayer with 100 mL of room temperature tap-water was used to rinse the soils that had adhered to the body part, and the rinse water was collected in the sample jar. Samples from each body part were collected in different jars. The rinse washing samples were delivered to the lab under refrigeration, and then stored at − 20 °C until analysis.

The rinse washing samples were placed in 15-mL centrifuge tubes and then centrifuged for 15 min at 3500 rpm to concentrate them. Soils condensed in the bottom of the tube were removed to a pre-weighed aluminum dish and dried in an oven at 105 °C overnight. After the sample had cooled, the aluminum dish was weighed again to determine the soil weight.

Tap water blank samples (n = 34) were also collected before each activity. The average soil weight of the blank sample was 1.28 ± 2.56 mg. For all rinse washing samples, we had used the values for blank samples to correct the results. For each activity, if the adhered soil weight was less than the blank value, it was replaced with 1/2 of the soil weight of the blank sample, which was collected before the activity. A verification of rinse washing sample was performed. We used 2 soil texture types, i.e., sand and clay, obtained from sites in the current study. The pre-weighted (0.1 g) soils (sand and clay) had adhered to the hand of an adult volunteer. The same collection method was used in children. Triplicates were completed for each soil weight and type. The mean recovery was 98.2 ± 0.03%.

2.3. Body surface area

We estimated the surface area of the children's hands, forearms, feet, and lower legs. The right and left sides were estimated separately. Because the rinse washing samples of the right and left sides of body parts were collected together, the total surface area of the body parts of both sides were used. Each child's hand was outlined using a pencil on paper. The picture was scanned into an image file. Measurements of the hand, i.e. the surface area, length, and width were estimated using AutoCAD LT® 2014 (Autodesk Inc., San Rafael, CA, USA). The hand surface area (HSA) was estimated based on Leckie et al. (2000). See Supporting information for details of the HSA estimation. The HSA was estimated by adding the surface areas of the five fingers and the total surface area of the palm.

The forearm surface area (FASA) and lower leg surface area (LGSA) were also assumed to be a cylinder. Only the sides of the forearm and lower legs were available for contact. The perimeter of the forearm was assumed to be equal to the average of the perimeter of the wrist and the perimeter of the elbow, and the perimeter of the forearm was assumed to be equal to the average of the perimeter of the ankle and the perimeter of the knee. The FASA and LGSA were respectively estimated using Eqs. (1) and (2):

$$\mathrm{FASA} = \left(\frac{\mathrm{WP} + \mathrm{EP}}{2}\right)\cdot\mathrm{FAL} \tag{1}$$

where FASA = forearm surface area (cm^2), WP = perimeter of the wrist (cm), EP = perimeter of the elbow (cm), FAL = length of the forearm