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Empirical Investigation of Hand-to-Mouth Transfer of Soil

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Estimates of risk attributable to soil contamination are often dependent upon assumed soil ingestion rates. Sources of ingestion rate estimates include calculation from assumptions regarding soil loading on hands, frequency of hand-to-mouth contact, and efficiency of transfer. For instance, Lepow et al. (1975) speculated that children might pass 10 mg of soil from hand to mouth 10 times per day, leading to ingestion of 100 mg of soil per day. Duggan and Williams (1977) produced a smaller estimate by assuming the relevant skin area involved only a part of one finger or a thumb, but also assumed 10 events per day. Alternative estimates derived from analyses of childrens' diets and excreta for elemental tracers (Calabrese and Stanek 1989, 1995; Davis et al. 1991) have since become available. However, those studies (which are subject to contradictory interpretation) do not explain the manner in which soil is ingested. Quantitative characterization of the process by which soil is transferred from children's hands to their mouths does not yet exist.

In the case of adult soil ingestion rates, even less information is available. Hawley's (1985) estimate of ingestion of up to 480 mg of soil by adults on "active" days is cited in the *Exposure Factors Handbook* (EPA 1990) and sometimes appears in risk assessments. It is based on the assumption that an individual might transfer half the soil in a 3.75 mg/cm2 layer covering the palmar side of the fingers and thumb of both hands from hand to mouth twice in a single day. Sheppard (1995) revisited Hawley's calculations and produced lower estimates primarily on the basis of lower assumed soil loadings. Prior soil ingestion estimates for both children and adults based on hypothetical exposure scenarios are summarized in Table 1.

Results of a laboratory-based examination of hand-to-mouth transfer of soil are reported here. This work was undertaken to provide an empirical basis for evaluating assumptions used to estimate masses of soil and contaminant that might be transferred from hand to mouth.

MATERIALS AND METHODS

Gravimetric methods used in prior laboratory and field experiments (Kissel et al. 1996a,b) were adapted for this study. The experimental protocol consisted of nine steps: 1) washing and thoroughly air drying the subject's hands, 2) loading one hand by pressing (palm down, fingers spread) into a shallow pan of soil, 3) mouthing three fingers above the first knuckle, 4) rinsing the mouth three times, 5) sucking the thumb, 6) rinsing the mouth three times, 7) licking the palm (three

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Table 1. Estimates of soil ingestion rates based on assumptions regarding hand-to-mouth transfer

Age [yrs]	In/Out[a]	Loading [mg/cm^2]	Area [cm^2]	Efficiency [-]	Event [mg/evt]	Frequency [evt/day]	Rate [mg/day]
Lepow et al. (1975)							
child		-	-	-	10	10	100
Duggan and Williams (1977)							
child		-	-	-	2	10	20
Hawley (1985)							
2.5	out	-	-	-	-	-	250
2.5	in	-	-	-	-	-	50-100
6	out	0.51	200	0.5	50	1[b]	50
6	in	0.056	56	1.0	3	1[b]	3
adult	out	3.75[c]	127	0.5	240	2[b]	480
adult	in[d]	1.8	127	0.5	110	1[b]	110
adult	in[e]	-	-	-	0.6	1[b]	0.6
Sheppard (1995)[f]					[mg/hr]	[hr/yr]	[mg/day][g]
2.5	out	0.5	-	-	20	1000	50
2.5	in	0.4	-	-	3	7760	60
6	out	0.5	-	-	10	700	20
6	in	0.04	-	-	0.15	5000	2
adult	out	1.0	-	-	20	300	20
adult	in	0.04	-	-	0.03	5000	0.4

[a]indoor or outdoor; [b]may refer to discrete events or to cumulative removal equivalent to those events; [c]misprinted as 3.5 mg/cm^2 in the original; [d]attic; [e]living space; [f]note change in units; [g]average annual day.

swipes with the tongue), 8) rinsing the mouth three times, and 9) washing the remainder of the soil from the hand. Mouths were rinsed to a funnel above a filter holder or a sample jar. Rinse water from the final hand wash was collected in a sample jar. The entire procedure was performed in triplicate on each of three occasions by each of four adult volunteers.

The soil used in the experiments was the sub 2 mm fraction of a locally obtained, natural loamy sand. The soil was autoclaved and stored at room temperature under foil. Arithmetic mean moisture contents of three samples taken prior to each trial ranged from 0.8-1.6 percent. Volunteers were encouraged to attempt to vary the amount of soil obtained via hand press to obtain a range of loading levels. Initial soil mass on the hand was determined as mass lost from the pan using a top-loading balance (A&D FP-6000) readable to 10 mg. Large funnels were placed in each filter holder (MFS, Cole-Palmer) or sample jar to aid sample collection. The filter holders were mounted on stainless steel vacuum manifolds (Nalgene) attached to a

vacuum pump (Gast 0523). All funnels/filters/sample jars were rinsed thoroughly using a 4-liter garden sprayer (Burgess, DB Smith & Co.) filled with deionized water (Nanopure). Wash water was filtered through 47-mm glass fiber filters with a nominal pore size of 0.5 µm (Gelman Metrigard). The pre-weighed filters were then placed in their corresponding aluminum weighing boats, oven dried (Labline L-C) overnight at 100°C, cooled in a dessicator (Sanplatec Dry Keeper) for a minimum of 1 hour, and weighed again on an analytical balance readable to 0.1 mg (Mettler College 150). The final hand wash involved use of a 2 percent solution of detergent (Liqui-Nox, Alconox).

Hand areas were calculated using correlations with height and weight (Anderson et al. 1985). Three males and one female participated in the study. The total surface area of both hands (front and back) was calculated from the equations:

$$SA_{hands,male} = 0.0257 \cdot W^{0.573} \cdot H^{-0.218}$$

$$SA_{hands,female} = 0.0131 \cdot W^{0.412} \cdot H^{0.0274}$$

where SA = surface area [m^2], W = weight [kg], and H = height [cm]. The area of a single hand was assumed to be one half the area of both hands. Hand loadings [mg/cm^2] reported below are based on the total surface area of one hand, although the loading occurred primarily on the palmar side.

Four subjects conducting three activities produced a total of 108 transfer measurements. Segregation by subject and activity gives 12 data sets of 9 outcomes each. Statistical analyses were conducted using SPSS® (version 6.1 for Windows®) (Norusis 1993). Data sets were evaluated for normality using the Lilliefors modification of the Kolmogorov-Smirnov (K-S) test and the Shapiro-Wilks (S-W) test (Norusis 1993). Results can be expressed in terms of either absolute mass or percent of possible mass (total hand loading) transferred. Normality of data expressed as mass could not be rejected (K-S $p > 0.15$, S-W $p > 0.11$) for 11 of 12 subject/activity (n=9) combinations. Percent data yielded similar results (11 of 12 K-S p-values > 0.14 and 10 of 12 S-W p-values > 0.09). All data sets segregated by both subject and activity are treated as normally distributed.

Aggregation of all subjects gives three sets of 36 outcomes (of both mass and percent data) for each activity. When subject-aggregated data were examined, normality was rejected ($p < 0.05$) for untransformed mass and percent data by at least one test (K-S or S-W) for five of six cases (n=36). Lognormality could not be rejected ($p > 0.06$) by either test for any of the aggregated log transformed mass or percent data. Consequently all subject-aggregated transfer data are treated as lognormal.

Mass recovery was assessed by comparison of the sum of the four mass measurements (thumb, palm, fingers, and residual) to mass loss from the pan. The arithmetic mean recovery in all experiments was 111 percent with a corresponding 95 percent confidence interval of 105 to 117 percent.

RESULTS AND DISCUSSION

Mean mass transferred from hand to mouth is presented by subject and activity in Table 2. Although some variability among subjects is evident, transfers were typically on the order of 10 mg per event. The same results expressed as a percentage of total mass on the hand are shown in Table 3.

Aggregate results for all subjects are presented in Table 4. The geometric mean mass that was recovered from volunteers' mouths after each activity ranged from 7.4 (thumb sucking) to 16.0 mg (palm licking). Corresponding fractions of the total soil mass on the hands ranged from 10.1 to 21.9 percent.

Soil mass transferred via thumb sucking and palm licking is plotted against hand loading in Figures 1 and 2, respectively. Subjects are distinguished by plot symbol. Not surprisingly, soil mass transferred to the mouth tends to vary directly with hand loading. Pre-transfer loadings (based on total hand area and mass loss from the pan) ranged between 0.04 and 0.35 mg/cm^2 in the experiments. (Since loadings were predominantly on the palmar side, average values on affected skin were roughly double the total hand values.) These whole-hand loadings are similar to values obtained from volunteers engaged in a variety of unstaged recreational and occupational activities (Kissel et al. 1996b; *Holmes et al. submitted for publication*). Therefore, although the activities used here were necessarily artificial, the hand loadings should be viewed as realistic.

Across all subjects, the percent of total pre-transfer hand load recovered from the mouth displayed a slight decline with increasing soil loading. Thumb sucking data are presented in Figure 3. The dashed line is a linear regression on the data. The associated coefficient of determination (r^2) is 0.14, indicating that the trend is weak. Palm (Figure 4) and finger (not shown) data are similar, exhibiting the same trend but with adjusted r^2 values less than 0.21. Results, when expressed as percent of total available mass, therefore appear relatively insensitive to mass loading. This raises the possibility of predicting transfers over a range of loadings if actual transfers can be determined at some known loading.

While such information is not yet available, the results presented here provide perspective on relevant processes. It appears that transfer of 10 or more mg of soil from a hand to the oral cavity in one event is possible, but requires moderate soil loading and more than incidental hand-to-mouth contact. The actual frequency of contact events that could be expected to produce transfers of this magnitude is unknown. Hand-to-mouth contacts exhibited by a small group (n=4) of California farm-worker children aged 2 to 4 have been tallied following videotaping (Zartarian et al. 1997). Those children exhibited individual median hand-to-mouth contact rates of 2 to 8 *per hand per hour* (data were reported separately for each hand). The maximum hourly rate observed was 46 for a single hand. Gross incidence rates are therefore likely to be higher than assumed by Lepow et al. (1975) and Duggan and Williams (1977) (Table 1). However, many of the observed contacts were less extensive than those tested here, involving only touching of the lips by some part of a hand without actual penetration of the oral cavity. Contacts resulting in insertion of part of either hand into the mouth were less frequent, ranging from 1 to 17 per hour (total for both hands) (*V. Zartarian, Stanford U., personal communication*), but that range still represents a relatively large number of opportunities for transfer. In addition, the tests reported here were conducted with adult volunteers. Because children have smaller hands, the same activities should result in the transfer of less soil mass given similar loading levels. Also, the fraction of soil transferred from hand to mouth that is subsequently swallowed is unknown but may be less than 100 percent. Therefore if unintentional (non geophagic) hand-to-mouth contact by children causes ingestion of roughly 100 mg/day of soil, it appears more likely to be the result of many small transfers than of 10 incidents as assumed by Lepow et al. (1975).

Table 2. Mass of soil (mg) recovered from mouths following each activity by subject (arithmetic mean[a] and corresponding 95% confidence interval)

	Subject			
Activity	1	2	3	4
Thumb sucking	8.7	5.9	8.8	9.9
	(5.6-11.8)	(3.9-7.8)	(4.6-13.1)	(5.9-14.0)
Finger mouthing	14.3	9.5	18.5	10.6
	(10.4-18.2)	(6.9-12.0)	(10.2-26.8)	(6.7-14.4)
Palm licking	20.4	18.9	18.2	13.1
	(13.6-27.1)	(13.3-24.5)	(11.5-24.8)	(8.9-17.3)

[a]n=9

Table 3. Percentage of total soil mass on the hand recovered from mouths following each activity by subject (arithmetic mean[a] and corresponding 95% confidence interval)

	Subject			
Activity	1	2	3	4
Thumb sucking	9.5	6.2	11.0	17.8
	(7.9-11.2)	(5.1-7.3)	(8.6-13.5)	(14.3-21.3)
Finger mouthing	16.2	10.3	23.4	19.3
	(13.5-18.9)	(8.4-12.3)	(18.5-28.2)	(14.1-24.4)
Palm licking	22.1	20.0	23.7	23.6
	(19.2-24.9)	(17.6-22.5)	(18.4-28.9)	(20.4-26.8)

[a]n=9

Table 4. Mass and fraction of total soil load on the hand recovered from mouths following each activity based on aggregate data from all subjects

	Mass [mg]		% Total mass on hand	
Activity	Geo mean[a]	95% CI	Geo mean[a]	95% CI
Thumb sucking	7.4	6.2-8.7	10.1	8.7-11.8
Finger mouthing	11.6	9.8-13.8	15.9	13.8-18.4
Palm licking	16.0	13.7-18.6	21.9	20.5-23.4

[a]n=36

Finally, adult volunteers in this study reported that the presence of roughly 10 mg of soil in the mouth is readily detected (and unpleasant). Repeated unintentional ingestion of that mass of soil by adults therefore seems unlikely. In light of this observation, the 480 mg per day estimate noted in Table 1 would require hundreds or perhaps thousands of hand-to-mouth contacts that resulted in soil transfer per day. Cigarette smokers might achieve that number of contacts, but whether their

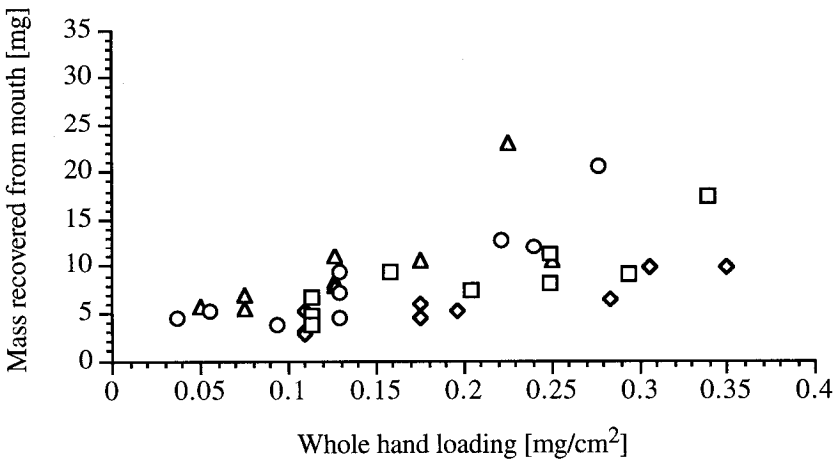

Figure 1. Soil mass recovered from the mouth following thumb sucking. (Symbols denote individual subjects, n=4.)

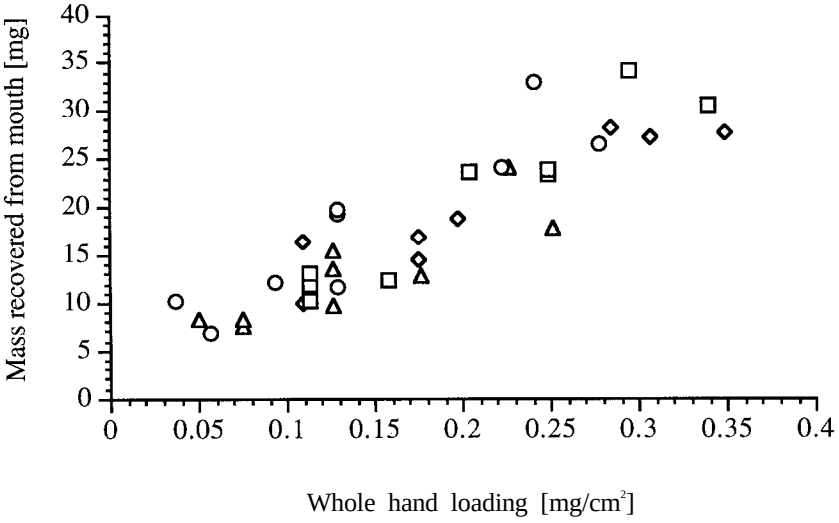

Figure 2. Soil mass recovered from the mouth following palm licking. (Symbols denote individual subjects, n=4.)

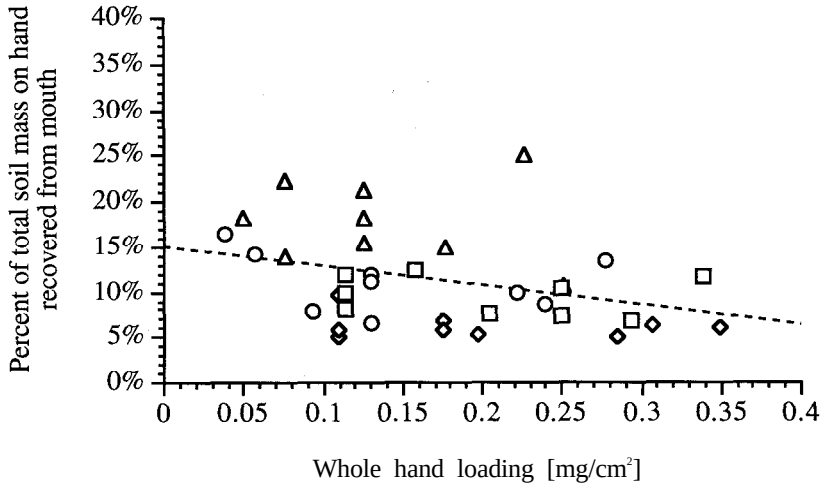

Figure 3. Variation in the fraction of the total soil mass on the hand recovered from the mouth following thumb sucking with hand loading. (Symbols denote individual subjects, n=4. Dashed line is linear regression.)

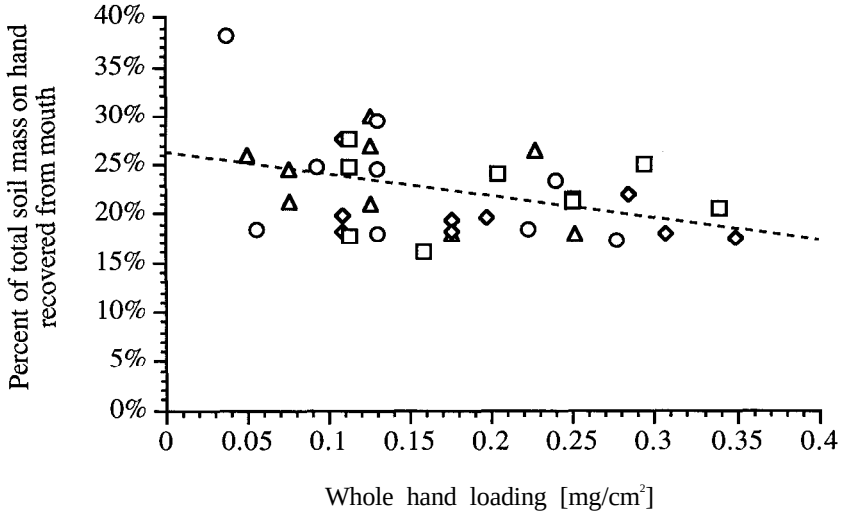

Figure 4. Variation in the fraction of the total soil mass on the hand recovered from the mouth following palm licking with hand loading. (Symbols denote individual subjects, n=4. Dashed line is linear regression.)

behavior produces consistent, non negigible soil transfers is unknown. At least for non smoking, non geophagic adults, the 480 mg/day estimate appears implausible.

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