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ORIGINAL ARTICLE

# Inadvertent ingestion exposure: hand- and object-to-mouth behavior among workers

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Contact between contaminated hands and the mouth or the area around the mouth (the perioral area) can result in inadvertent ingestion exposure. Exposure by this route is known to occur among children, but adults may also be exposed. Observations of 48 workers were carried out in 8 UK worksites to study hand- and object-to-mouth behavior. Each subject was observed in real-time for ~60 min during normal work activities. Each contact was recorded along with information about time of contact, glove use, respirator use, task and object type. Subjects were interviewed to gather information about smoking, nail biting and risk perception. The effects of factors (glove use, respirator use, smoking, nail biting, risk perception, work sector and task group) on contact frequency were assessed using non-parametric tests and Poisson regression models. Several determinants of contact frequency were identified, including time spent "between" work tasks, glove and respirator use, smoking and nail biting. Hand-to-mouth contact frequencies were particularly high while workers were "between" work tasks (23.6 contacts per hour, compared with the average contact frequency of 6.3 per hour). The factors that were related to contact frequency differed between object- and hand-to-mouth contacts, suggesting that these should be considered separately. These findings could be used for developing exposure models, to inform measurements of inadvertent ingestion among adults and to identify control strategies.

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## INTRODUCTION

Contact between contaminated hands and objects and the mouth can lead to ingestion of hazardous materials. This exposure route has been called inadvertent ingestion exposure.[1,2] The majority of the work that has studied inadvertent ingestion has focused on children, especially infants and toddlers.[3–6] Although the behavior decreases with age,[7,8] contact with contaminated hands and objects could also be a route of exposure for adults. This could be particularly important in occupational settings where people may be exposed to higher quantities of toxic materials than they are likely to encounter in the community. Cherrie et al.[1] estimated that 16% of the working population of the United Kingdom may be exposed to hazardous materials (including metals, pharmaceuticals and pathogens) by inadvertent ingestion. In community settings, hand- or object-to-mouth behavior may be a pathway of disease transmission for both children and adults.

Exposures of children to pesticides and soil contaminants arising from hand- and object-to-mouth contact have been estimated using observational data on the frequency of this behavior for different groups of children.[6,9,10] Similar estimates have been attempted for inadvertent ingestion exposure among adults, but data that can be used to estimate contact frequencies are sparse. Some models have used contact frequencies that were based on professional judgment[11–13] and others have used data from observations of children.[9,14,15]

Three previous studies have examined hand-to-mouth behavior among adults. Nicas and Best[16] videotaped volunteers sitting at a desk performing office work. The average number of contacts per hour was 8.0 (SD 8.0) and ranged from 0 to 24, indicating a wide range of contact frequencies across the 10 volunteers. Personal characteristics associated with contact frequency were not studied; however, subjects who touched their lips frequently also touched their noses and eyes frequently.

Zainudin[17] and Christopher[18] studied contact between the perioral area (the lips and the area surrounding the mouth) and hands and objects in occupational settings. They rated hand "busyness" (the degree to which hands were used to carry out work tasks) during the observation period and found that workers whose hands were busier during work tasks exhibited significantly lower rates of contact with the perioral area. Zainudin[17] investigated differences between job groups and found that office workers had a higher median frequency of perioral contact relative to laboratory and manufacturing/engineering workers.

Smoking and nail biting are related to inadvertent ingestion exposure. Smoking at work has been positively associated with the concentration of metals in biological samples,[19–22] and bitten nails and visible dirt under fingernails have been anecdotally linked to increased blood levels.[23] The effects of other factors on contact frequency have not been studied (e.g., use of gloves and respiratory protective equipment, frequency and duration of breaks). Risk perception may have an effect on contact frequency if workers who believe the substances they are working with are hazardous to health and avoid touching their mouths while at work, but this has not been studied. Object-to-mouth contact frequency has been understudied and the types of objects that

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are likely to be involved in contact in work environments remain unidentified. Moreover, although there is evidence that hand busyness during work tasks has an effect on hand/object-to-mouth behavior, all of the studies that have been carried out so far have only observed workers while they are actively engaged in work tasks. In reality, workers spend much of their day between tasks (e.g., waiting, talking and moving from one area to another) and contact frequency during this time has not been studied. As the hands may be more free between tasks, inadvertent ingestion exposure may be particularly likely in between tasks.

This study was carried out as part of a project to develop a predictive model for estimating exposure from inadvertent ingestion. The aim of this study was to increase the state of knowledge of hand/object-to-mouth behavior among adults in occupational settings and to identify factors that affect the number and type of hand/object-to-mouth contact among workers. Within this overall aim, the study addressed five specific research questions:

1. What types of objects are typically inserted in or placed near the mouths of workers?
2. How is hand/object-to-mouth behavior affected by the use of personal protective equipment (PPE), specifically gloves and respirators?
3. How often do workers typically touch their mouth in time periods between work tasks and how does this differ from their hand/object-to-mouth behavior during work tasks?
4. How is the hand/object-to-mouth contact frequency affected by workers' perception of the risk posed by the substances being handled?
5. How is the hand/object-to-mouth contact frequency affected by personal factors including smoking, nail biting and facial hair?

## METHODS

### Recruitment

Companies were recruited using the authors' network of industry contacts and a recruitment email sent to a British occupational hygiene group (UKOH). Five UK companies were recruited and work was carried out at eight worksites within these companies. Industries identified by Cherrie et al.[1] as particularly prone to inadvertent ingestion exposure were targeted; for example, industries in which there may be exposure to metals, pathogens or high-molecular-weight allergens. The main focus of the recruitment effort was on industrial worksites, where exposures were expected to be highest, but one laboratory setting was also recruited for comparison. Company staff assisted observers to identify workers who were potentially exposed. At each worksite, observers aimed to observe as many exposed workers as possible. One or two observers were present at each worksite for one to four shifts in total.

Workers were informed that the purpose of the research was to study exposures in the workplace during normal work activities and the ways that these exposures may occur. To avoid influencing their behavior, workers were not made explicitly aware that the research was focused on hand/object-to-mouth exposure before all research at their worksite was complete. Workers were advised that the observers would not interfere with their normal work activities and that observations would remain anonymous. Participating workers were entered into a prize draw to win one of four retail vouchers worth £50 each. Participants gave informed consent. Ethical approval for the observational work was obtained from the University of Aberdeen College Ethics Review Board (Certificate Number: CERB/2011/5/619).

### Observational Methodology

In order to capture workers both during and between work tasks, researchers aimed to observe each worker for 60 min. This is the longest period previously reported in the literature for observations of hand/object-to-mouth contact among workers.[17] Unlike previous studies, specific task activities were not targeted. Instead, workers were observed at any stage throughout the day to capture a "snapshot" of their workday. To avoid infringing on workers' personal time, workers were not observed during formal breaks (e.g., lunch breaks). If a worker went on a formal break, the observation was either terminated at that point or, if possible, it was paused and resumed after the break. Twenty percent of participants were observed for two 60-min durations (repeats) to assess within-worker variation. Observations were carried out in real time. Previous studies of hand/object-to-mouth behavior among adults indicated that frequencies of contact were typically $< 10$ per hour.[16,17] At this low contact frequency, it is possible for observers to record real-time information. All observations were carried out by one of two researchers (Observers A and B). Ten percent of all observations were carried out simultaneously by both researchers to evaluate between-assessor agreement. The two observers carried out pilot observations on office and laboratory workers before data collection to refine the observational technique.

During observations, the observer "shadowed" the observed worker at an approximate distance of 2–5 m and recorded each hand/object-to-mouth contact on an iPod Touch (Apple, Cupertino, CA, USA) using the application Contraction Timer Deluxe (Deltaworks, www.delworks.com). The intended use of this application is to time contractions associated with childbirth but it was suitable for tracking hand-to-mouth contacts because it could record the times when a contact began and ended. This allowed observers to determine the time and duration of contacts, and the duration of time between successive contacts. Contextual information about hand/object-to-mouth contacts was also recorded on paper forms (Figure 1).

The following definitions were used:

Perioral area: The lips and the area within 2 cm of the lips.

Oral cavity: The area between the lips and the interior of the mouth including the gums, teeth and tongue.

Mouth: Both the perioral area and the oral cavity

Manual task: A task requiring the worker to engage their hands or body in the work (e.g., operating a lathe, spray painting and packing).

Desk or paperwork: Work performed at a desk or a table that involves working with paper, working on a computer and/or talking on the phone.

Operate machinery: Using controls or a computer to operate machinery to complete a task (e.g., driving a loader, operating a sprayer from a control booth).

Between task: Periods when the worker is not mentally or physically engaged in a work task, but is not on a formal break. This can include breaks for drinks, cigarettes or sanitation, waiting, travelling through the facility and speaking to co-workers.

Subjects sometimes moved their hand to different positions during a contact. These contacts were counted separately if (i) there were more than two seconds between contacts; (ii) the hand or object contacted a surface in between contacts; or (iii) the hand or object moved from the perioral area to the oral cavity (or vice versa).

At the end of the observation period, the observer(s) estimated the amount of time that the worker spent in each of four task categories ("manual task", "desk or paperwork", "operate machinery" or "between task").

Worker risk perception was assessed by asking workers to describe how hazardous to health ingestion of half a teaspoonful of a series of substances would be on a visual analog scale from 1 (unlikely to make you ill) to 10 (likely to make you ill). The substance that the workers may have been exposed to was included in the list along with a number of other substances ranging from relatively innocuous (e.g., calcium) to hazardous (e.g., lead). The substances varied by worksite to reflect potential exposures. This approach allowed an assessment of the worker's perception of

| Time | Task | Area | Contact Surface | PPE | Type of Object | Notes |
|---|---|---|---|---|---|---|
| | □ Manual Task<br>□ Desk or Paperwork<br>□ Operate Machinery<br>□ Between Task | □ Perioral<br>□ Oral | □ Hand<br>□ Arm<br>□ Object | □ Glove<br>□ Shirt<br>□ RPE | □ Tool<br>□ Pen<br>□ Paper<br>□ RPE<br>□ Other | |

**Figure 1.** Hand/object-to-mouth contextual information form (RPE, respiratory protective equipment).


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**Table 1.** Number of observation sessions by worksite.

| *Company* | *Worksite* | *Number of observation sessions* | | | |
|---|---|---|---|---|---|
| | | *First* [a] | *Repeat*[b] | *Co-observation*[c] | *Total*[d] |
| A | Animal Research Laboratory | 11 | 0 | 1 | 12 |
| B | Precious Metals Smelter | 5 | 0 | 0 | 5 |
| C | Engine Repair Facility | 11 | 7 | 3 | 21 |
| | Engine Manufacturing Facility | 4 | 3 | 1 | 8 |
| D | Coal Power Station 1 | 5 | 0 | 1 | 6 |
| | Coal Power Station 2 | 4 | 0 | 0 | 4 |
| E | Steel Processing and Coating facility | 5 | 1 | 0 | 6 |
| | Steel Production Facility | 2 | 1 | 0 | 3 |
| Overall | | 48 | 12 | 6 | 65 |

[a]First: The first observation that was carried out on a subject. In the case of co-observations, one of the two observations is classified as "First" and one is classified as "Co-observation" in this table. [b]Repeat: Observations that were the second observation performed on a subject who had previously been observed. [c]Co-observation: Observations that were carried out alongside one of the "First" observation and on the same subject. [d]Total: All observations including first observations, repeats, co-observations.

the risk of ingestion of the substance they were working with, without suggesting that the substance was hazardous. Workers were also asked whether they habitually smoked or bite their nails, and the presence of absence of facial hair was recorded. These questions were asked after the observational period was complete. The questions were adapted from those used by Christopher.[18]

### Statistical Analysis

Hourly contact frequencies were calculated for hand-to-oral, hand-to-perioral, arm-to-oral, arm-to-perioral, object-to-oral and object-to-perioral contact, and for the frequency of overall contact with the mouth. Workers were occasionally out of the observers' view when they entered areas where the observer was not able to follow such as a small space, an area with safety restrictions or toilet facilities. The duration of such periods was subtracted from the observation duration. As the focus of the study was on inadvertent ingestion exposure (as opposed to ingestion in general) contacts with food and drink materials were not included in final calculations.

The frequency of contacts in each task category was estimated for each worker by dividing the number of contacts that occurred while the worker was performing the task by the amount of time that the worker spent in that task category. The same approach was used to estimate the frequency of contacts, while gloves and respirators were and were not used by individual workers.

The side-by-side simultaneous observations carried out by the two assessors were compared in the Wilcoxon signed-rank test and Spearman's correlation. Differences in frequencies of contact between different groups (e.g., those who did and did not use PPE, workers who spent more or less time "between task") were compared using Kruskal–Wallis tests with multiple comparisons with rank sums used for *post-hoc* comparisons. Among workers who did use PPE, the frequency of contacts during times when workers were and were not using PPE was compared using Wilcoxon signed-rank tests. Wilcoxon signed-rank test was also used to compare contact frequencies for repeat observations. Non-parametric tests were selected because the count data did not follow a normal distribution. All factors were combined in Poisson regression models with frequency of hand- or object-to-mouth contacts as the outcome variables and the explanatory variables added as factors. The Poisson distribution was selected because the outcome variable was a frequency. Examination of the distribution of the model residuals and fitted values indicated a good fit to the data. Statistical significance was defined as $P < 0.05$. Statistical analyses were conducted with Minitab (Minitab, State College, Pennsylvania, USA) and Genstat 15th Edition (VSN International, Hemel Hempstead, UK).

## RESULTS

### Sample Population

Sixty-five observations of 48 workers were carried out at 8 UK worksites belonging to 5 companies between March and August of 2012. Five of the worksites were manufacturing facilities where workers were potentially exposed to metals, one was an animal research facility where workers were potentially exposed to animal dander and two were coal-fired power stations with potential exposure to coal dust and engine oils. All workers who were approached agreed to participate. Twelve repeat observations were conducted and six observations were carried out simultaneously by two observers. Details of the number of observations taken by worksite are provided in Table 1. The observations ranged in duration from 25 to 61 min. Only two observations were $< 40$ min and 71% were of 59–61 min duration. Some observations were $< 60$ min, because time was subtracted from the observation duration when workers went out of the observer's view. The majority of the observed workers were males, reflecting the workforce of the sites monitored. The five female workers were all at company A (an animal research laboratory).

### Observer Agreement and Repeated Measurements

There were no significant differences between the two assessors in side-by-side co-observations ($P = 0.463$) and the contact frequencies recorded by the two observers were highly correlated ($r = 0.99$). The data from the two observers were combined due to their similarity. When co-observations were done ($n = 6$), data from observer A was consistently used in analysis to avoid repetition of these observations in the data set. Where individual workers had been studied on two separate occasions ($n = 12$), the within-worker variability was similar to the between-worker variability; thus, repeats were considered as separate observations in all analysis. Key analyses were also repeated using one randomly selected measurement for the workers for whom repeat measures were available.

### Overall Frequencies of Contact

The average frequencies for the different types of contacts calculated are presented in Table 2. The majority of contacts that occurred were between the hands and the perioral area. Objects were also brought into contact with the perioral area more frequently than the oral cavity.

### Object-to-Mouth Contact

The objects involved in contact are catalogued in Table 3. The number of total contacts recorded involving each of the object types is presented along with the number of observations (out of the 59 carried out) during which each object was involved in contact. The objects that were involved most frequently in

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object-to-perioral contact were respirators (they were rested on the lip or chin, or brushed against the perioral area when being put on or off). Glasses (including spectacles and eye protection) were the objects most frequently placed in the oral cavity.

### Factors Related to Contact Frequency

The average, median and maximum contact frequencies by several categorical factors are presented for hand-to-mouth contact in Table 4 and for object-to-mouth contact in Table 5.

### PPE Use

There were no significant differences in the hand- or object-to-mouth contact frequency between workers who did and did not use gloves during the observation period. However, there were only five workers who did not use gloves. Among workers who did use gloves, the frequency of hand-to-mouth contacts during the time when they were not using gloves (mean = 4.8 per hour) was significantly higher than during the time when gloves were used (mean = 1.2 per hour). The same pattern was seen for object-to-mouth contact.

There were also no significant differences between workers who did ($n = 31$) and did not ($n = 28$) use respirators. When respirators were worn for part of the time, the average hand-to-mouth contact frequency was higher when respirators were not worn (5.3 per hour) than when respirators were worn (0.1 per hour). The opposite was observed for object-to-mouth contact. The average frequency of object-to-mouth contact was 1.6 per hour during times when respirators were used and 0.2 per hour when respirators were not used; these differences were statistically significant. Of the 31 workers who used respirators, 13 used disposable dust masks, 9 used powered air-purifying helmets, 1 wore a half-face respirator, 1 wore a full-face respirator and 8 wore face coverings that are not used to protect breathing but were classified as respirators in this assessment because they cover the face (6 used paper masks and 2 used face visors). There were insufficient data available to examine differences in contact frequencies between respirator types.

**Table 2.** Frequency of contact between the mouth and hands, objects and arms (number of observations = 59).

| *Type of contact* | *Frequency of contact per hour* | | |
|---|---|---|---|
| | *Average* | *Median* | *Maximum* |
| Hand-to-oral | 0.4 | 0.0 | 17.0 |
| Hand-to-perioral | 5.8 | 4.0 | 26.0 |
| Hand-to-mouth (oral or perioral) | 6.3 | 4.0 | 26.0 |
| Object-to-oral | 0.5 | 0.0 | 14.3 |
| Object-to-perioral | 1.1 | 0.0 | 11.8 |
| Object-to-mouth (oral or perioral) | 1.6 | 0.0 | 14.3 |
| Arm-to-oral | 0.0 | 0.0 | 0.0 |
| Arm-to-perioral | 0.1 | 0.0 | 3.0 |
| Arm-to-mouth (oral or perioral) | 0.1 | 0.0 | 3.0 |
| Total contacts | 7.9 | 6.0 | 30.0 |

### Task Categories

The average frequency of hand-to-mouth contact "between tasks" was 23.6 per hour. This was significantly higher than the other task categories (manual task = 2.8, desk or paperwork = 8.4 and operating machinery = 2.9), which were not significantly different from each other. To explore this further, workers were split into three groups based on the percentage of the observation period that was spent "between tasks": $< 10\%$, 10–30% and $> 30\%$. The $< 10\%$ and $> 30\%$ categories represent the bottom and top quartiles, respectively. The two middle quartiles were merged because the data distribution did not allow these quartiles to be split evenly (22 out of the 31 observations in this category were either 10% or 15%). The contact frequencies were compared across the three groups. The average and median contact frequencies increased in the categories with a higher proportion of time "between tasks" and these differences were significant. Differences between object-to-mouth contact frequencies by task category were significant in the Kruskal–Wallis test, but none of the groups were significantly different from each other in the *post-hoc* test. Frequency of object-to-mouth contact was highest in the "between task" category (9.9 contacts per hour). There was no difference in object-to-mouth contact frequency between workers who spent different percentages of the observation period "between tasks".

### Risk Perception

The workers were grouped into a high- and low-risk perception groups based on the highest health risk score allocated by each worker to substances they were potentially exposed to. The high- and low-risk perception groups comprised workers with risk perception scores above and below the average score for all workers (mean = 7, SD = 3), respectively. The hand-to-mouth contact frequency was significantly higher among workers in the high-risk perception group (score $> 7$). There was no relationship between risk perception and object-to-mouth contact.

### Work Sector

Worksites were divided into two work sectors: industrial (sites B, C, D and E) and research (site A). The frequency of hand-to-mouth contact was significantly higher at industrial work sites (mean = 7.6 per hour) than at the research laboratory (mean = 0.5 per hour). The opposite was seen for object-to-mouth contact, with an average frequency of object-to-mouth contact of 3.0 per hour at the research laboratory and. 1.3 per hour at the industrial worksites ($P = 0.086$).

**Table 3.** Total number of observed contacts for each object across all 65 observation sessions and the number of observation sessions during which the objects were observed to be involved in contact.

| | | *Glasses* | *Glove* | *Tape* | *Pen or pencil* | *Cigarette* | *Pill* | *Respirators* | *Key* | *Tissue* | *Phone* | *Earmuff* | *Lanyard* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Object-to-perioral | *N* total contacts[a] | 1 | 2 | 0 | 1 | 0 | 0 | 49 | 1 | 2 | 6 | 2 | 2 |
| | *N* observations[b] | 1 | 2 | 0 | 1 | 0 | 0 | 11 | 1 | 2 | 3 | 1 | 1 |
| Object-to-oral | *N* total contacts[a] | 10 | 1 | 1 | 8 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *N* observations[b] | 5 | 1 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

[a]*N* total contacts: The number of times the object was observed to be involved in a contact across all observation sessions (e.g., there were 10 observed instances of glasses-to-oral contact). [b]*N* observation: The number of observation sessions during which the object was observed to be involved in contact (e.g., there were five observation sessions during which the subjects' glasses contacted their oral cavity).


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**Table 4.** Frequency of hand-to-mouth contact per hour by work-related and personal factor categories.

| *Factor* | *Categories* | N | *Frequency of contact per hour*[a] | | | P-*value* |
|---|---|---|---|---|---|---|
| | | | *Average* | *Median* | *Maximum* | |
| Any glove use | Used[b] | 54 | 6.4 | 4.3 | 26.0 | 0.753 (Kruskal–Wallis) |
| | Not used | 5 | 5.0 | 2.9 | 12.3 | |
| Periods of time when gloves were used among "gloves used" ($N = 54$) | Time while on | — | 1.2 | 0.0 | 12.0 | $< 0.001$ (Wilcoxon signed-rank) |
| | Time while off | | 4.8 | 3.1 | 25.0 | |
| Any respirator use | Used[b] | 31 | 5.5 | 2.6 | 26.0 | 0.083 (Kruskal–Wallis) |
| | Not used | 28 | 7.1 | 6.5 | 25.0 | |
| Periods of time when respirators were used among "gloves used" ($N = 31$) | Time while on | — | 0.1 | 0.0 | 1.0 | $< 0.001$ (Wilcoxon signed-rank) |
| | Time while off | | 5.3 | 2.6 | 26.0 | |
| Task category | Manual task | 57 | 2.8 | 0.0 | 40.0 | $< 0.001$ (Kruskal–Wallis) |
| | Desk or paperwork | 43 | 8.4 | 0.0 | 60.0 | |
| | Operate machinery | 29 | 2.9 | 0.0 | 29.5 | |
| | Between task | 55 | 23.6[c] | 18.0 | 140.0 | |
| % of time "between task" | $< 10$ | 14 | 1.7 | 0.5 | 12.3 | $< 0.001$ (Kruskal–Wallis) |
| | 10–30 | 31 | 6.7 | 5.0 | 26.0 | |
| | $> 30$ | 14 | 9.8[d] | 7.8 | 25.0 | |
| Work sector | Industrial | 48 | 7.6 | 6.5 | 26.0 | $< 0.001$ (Kruskal–Wallis) |
| | Research | 11 | 0.5 | 0.0 | 4.0 | |
| Highest risk score | 1–7 | 19 | 2.9 | 1.0 | 17.0 | 0.001 (Kruskal–Wallis) |
| | 8–10 | 40 | 7.9 | 6.5 | 26.0 | |
| Smoker | No | 41 | 4.6 | 2.9 | 25.0 | 0.006 (Kruskal–Wallis) |
| | Yes | 18 | 10.1 | 8.0 | 26.0 | |
| Nail biter | No | 43 | 5.0 | 3.0 | 21.0 | 0.027 (Kruskal–Wallis) |
| | Yes | 16 | 9.5 | 8.5 | 26.0 | |
| Facial hair | No | 40 | 6.3 | 4.0 | 26.0 | 0.820 (Kruskal–Wallis) |
| | Yes | 19 | 6.3 | 4.5 | 21.0 | |

[a]All minimum values = 0. [b]Used: gloves or respirators were used at all during the observation period, not used: they were not used at all during the observation period. [c]"Between task" category significantly different from all other task categories in multiple comparisons with rank sums. [d]"$> 30$" Group significantly different from "$< 10$" and "10–30" groups in multiple comparisons with rank sums.

### Personal Factors

Smoking and nail biting were related to hand-to-mouth contact frequency, but not object-to-mouth. Smokers had significantly higher overall frequencies of hand-to-mouth contact (mean = 10.1 per hour) than non-smokers (mean = 4.6 per hour). Similarly, nail biters had significantly higher frequencies of hand-to-mouth contact (mean = 9.5 per hour) than non-nail biters (mean = 5.0 per hour). There was no relationship between the presence of facial hair and the frequency of contact.

### Multivariate Analysis

Poisson regression models for hand-to-mouth and object-to-mouth contact frequency were fitted to examine the concurrent effects of the explanatory factors, respectively. Risk perception group and work sector were highly correlated, with all except one worker from the research laboratory in the low-risk perception group. As a result, the effect of risk perception (high *vs* low) was nested within work sector and comparisons made only for the industrial sites. The results are presented in the form of coefficients and associated *P*-values from the regression model in Table 6. Positive coefficients indicate an increase in the number of contacts.

A significant association was seen between hand-to-mouth contact frequency and % time between categories, nail biting status and smoking status. Hand-to-mouth contact frequencies increased with increasing percentage of time "between task" and were higher among nail biters and smokers. There were borderline significant relationships seen for risk score category (in the industrial work sector only) and respirator use. In the industrial work sector, workers in the low-risk perception group (risk score $< 8$) had a lower rate of hand-to-mouth contact in the high-risk perception group, but this was not statistically significant ($P = 0.061$). Workers who wore respirators at any time during the observation period had a higher rate of hand-to-mouth contact, but this was also not significant ($P = 0.078$).

Results for object-to-perioral contact were different, with an association only with respirator use and glove use. Frequency of object-to-mouth contact was higher among those who used respirators and lower among those who used gloves.

As there were relatively few data points from workers in the research laboratory, a second analysis was carried out, which considered only industrial workers. Results from this analysis were very similar. Secondary analyses were also carried out in which repeat measurements were removed from the data set and the results were again similar to those for the data set as a whole.

## DISCUSSION

Observations of workers were carried out to study hand- and object-to-mouth behavior during work activities. Workers were

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**Table 5.** Frequency of object-to-mouth contact per hour by work-related and personal factor categories.

| *Factor* | *Categories* | N | *Frequency of contact per hour*[a] | | | P-*value (statistical test)* |
|---|---|---|---|---|---|---|
| | | | *Average* | *Median* | *Maximum* | |
| Any glove use | Used[b] | 54 | 1.6 | 0.0 | 14.3 | 0.498 (Kruskal–Wallis) |
| | Not used | 5 | 1.5 | 1.4 | 3.9 | |
| Periods of time when gloves were used among "gloves used" ($N = 54$) | Time while on | — | 0.0 | 0.0 | 0.1 | $< 0.001$ (Wilcoxon signed-rank) |
| | Time while off | | 1.3 | 0.0 | 14.3 | |
| Any respirator use | Used[b] | 31 | 2.4 | 1.0 | 14.3 | 0.067 (Kruskal–Wallis) |
| | Not used | 28 | 0.7 | 0.0 | 3.9 | |
| Periods of time when respirators were used among "respirator used" ($N = 31$) | Time while on | — | 1.6 | 0.0 | 11.8 | 0.014 (Wilcoxon signed-rank) |
| | Time while off | | 0.2 | 0.0 | 2.3 | |
| Task category | Manual task | 57 | 1.4 | 0.0 | 20.0 | 0.005[c] (Kruskal–Wallis) |
| | Desk or paperwork | 43 | 1.0 | 0.0 | 20.0 | |
| | Operate machinery | 29 | 1.0 | 0.0 | 13.3 | |
| | Between task | 55 | 9.9 | 0.0 | 300.0 | |
| % of time "between task" | $< 10$ | 14 | 2.3 | 1.0 | 11.8 | 0.236 (Kruskal–Wallis) |
| | 10–30 | 31 | 1.6 | 1.0 | 14.3 | |
| | $> 30$ | 14 | 0.8 | 0.0 | 6.0 | |
| Work sector | Industrial | 48 | 1.3 | 0.0 | 14.3 | 0.086 (Kruskal–Wallis) |
| | Research | 11 | 3.0 | 1.0 | 11.8 | |
| Highest risk score | 1–7 | 19 | 2.0 | 1.0 | 11.8 | 0.450 (Kruskal–Wallis) |
| | 8–10 | 40 | 1.4 | 0.0 | 14.3 | |
| Smoker | No | 41 | 1.7 | 0.0 | 14.3 | 0.880 (Kruskal–Wallis) |
| | Yes | 18 | 1.3 | 0.5 | 7.0 | |
| Nail biter | No | 43 | 1.5 | 0.0 | 11.8 | 0.832 (Kruskal–Wallis) |
| | Yes | 16 | 1.8 | 0.5 | 14.3 | |
| Facial hair | No | 40 | 1.8 | 0.5 | 14.3 | 0.375 (Kruskal–Wallis) |
| | Yes | 19 | 1.0 | 0.0 | 7.0 | |

[a]All minimum values = 0. [b]Used: gloves or respirators were used at all during the observation period, not used: they were not used at all during the observation period. [c]No pairwise comparisons statistically significant in multiple comparisons with rank sums.

observed in real time by one or two researchers for about 60 min at a time while carrying out their normal work activities. Researchers recorded each hand- or object-to-mouth contact along with information about the contact and work activities (including glove and RPE use, type of task carried out and duration of contact). The observational data were analyzed to identify determinants of hand/object-to-mouth behavior.

Previous observational studies of adults have identified hand busyness as an important determinant of hand-to-mouth behavior.[17,18] This study identified several additional determinants. A major strength of the study was the hour-long observation period that allowed comparison of different task categories and the time spent "between tasks". This also enabled a comparison of contact frequencies within subjects when PPE was and was not worn. This is also one of the few studies of observational data on hand/object-to-mouth behavior among adults. Although behavior in a work setting likely differs from a home or community setting, these findings are probably more relevant for all adults than the findings of observations of children.

One of the main limitations was the possible effect of the observers' presence on subject behavior. The presence of an observer is known to influence the behavior of a subject and it is unclear how this may have affected the findings.[24] The effect was minimized by keeping subjects unaware of the interest in hand/object-to-mouth behavior. Real-time observations were conducted instead of video monitoring or collection of closed-circuit television (CCTV) footage because many worksites restrict photography and videography, and access to CCTV footage; thus, the use of video data would have limited the number of companies willing to participate in the study. Furthermore, the less intrusive the observation is to the privacy of the subject, the smaller the effect on subject behavior.[24] Direct observation may have been less intrusive than the presence of a video camera. CCTV footage is a potentially large untapped source of observational information. If footage from these cameras were available for research then it would decrease the time required for researchers to collect observational data. Although worker behavior may be slightly altered when CCTV is present, these monitoring systems are typically in place permanently so that workers would be accustomed to their presence and their behavior would be altered less than direct observation by a researcher.

Recruitment of companies to participate in this study was challenging, as there were few obvious benefits to the participating company, and because some time was taken from each participating worker's day to provide informed consent and complete post-observation questionnaires. The companies that agreed to participate were all relatively large companies (greater than 100 employees) that employed in-house health and safety staff. Although none of the companies provided training to workers on inadvertent ingestion exposure, the workers at these companies may have received more general health and safety


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**Table 6.** Multivariate Poisson regression analysis.

| *Variable*[a] | N | *Hand-to-mouth* | | *Object-to-mouth* | |
|---|---|---|---|---|---|
| | | *Coefficient*[b] | P-*value*[c] | *Coefficient*[b] | P-*value*[c] |
| Constant | | 1.4 | < 0.001 | 0.42 | 0.295 |
| *Work sector* | | | | | |
| Industry | 48 | Ref | | Ref | |
| Research | 11 | − 6.8 | 0.518 | − 0.77 | 0.464 |
| *Risk score category within work sector – Industry* | | | | | |
| High | 39 | Ref | | Ref | |
| Low | 9 | − 0.29 | 0.061 | − 0.66 | 0.133 |
| *Risk score category within work sector—Research* | | | | | |
| High | 10 | Ref | | Ref | |
| Low | 1 | 4.7 | 0.653 | 1.1 | 0.280 |
| *% Time between task categories* | | | | | |
| < 10% | 14 | − 0.46 | 0.048 | 0.13 | 0.705 |
| 10–30% | 31 | Ref | | Ref | |
| > 30% | 14 | 0.30 | 0.022 | − 0.2 | 0.569 |
| *Any respirator use (all workers)* | | | | | |
| No | 28 | Ref | | Ref | |
| Yes | 31 | 0.22 | 0.078 | 1.3 | < 0.001 |
| *Any glove use (all workers)* | | | | | |
| No | 5 | Ref | | Ref | |
| Yes | 54 | − 0.06 | 0.784 | − 1.0 | 0.030 |
| *Nail-biting status* | | | | | |
| Non-nail biter | 43 | Ref | | Ref | |
| Nail biter | 16 | 0.82 | < 0.001 | 0.24 | 0.339 |
| *Smoking status* | | | | | |
| Non-smoker | 18 | Ref | | Ref | |
| Smoker | 41 | 0.74 | < 0.001 | 0.19 | 0.463 |

Abbreviation: Ref, reference group. Coefficients presented for models of hand-to-mouth and object-to-mouth contact. [a]All variables are categorical. [b]A positive coefficient indicates an increase in the number of hand-to-mouth or object-to-mouth contacts. [c]A *P*-value < 0.05 indicates a coefficient which is statistically significantly different from zero.

training than workers at small and medium-sized enterprises (SMEs). Risk awareness, PPE use habits and hand/object-to-mouth contact frequencies may differ among workers at SMEs.

The majority of contacts observed were with the perioral area rather than the oral cavity (Table 2). Of the previous studies of hand-to-mouth behavior among adults, only Christopher[18] differentiated between perioral and oral contact. Christopher[18] found that the mean rates of perioral and oral contact were similar to each other (2.9 and 2.4 per hour, respectively). The observation durations in that study were lower (10–20 min) and subjects were only observed during work tasks; hence, the findings of the current study may be more relevant to the overall pattern of contact throughout the work day. If perioral contacts occur more frequently than oral contacts, this may have implications for exposure measurement, modeling and control. Owing to the continual flux of saliva through the mouth, measuring the inadvertent ingestion exposure directly can be difficult.[18] If much of the exposure comes via the perioral area, it may be possible to measure exposure on the perioral area, using standard dermal exposure measurement methods, as a surrogate for inadvertent ingestion. The findings related to perioral contacts reinforce the findings of Christopher[18] who also concluded that, due to a better association between actual and estimated perioral exposure compared to that of predicted and measured oral exposure, perioral is probably a better indicator of inadvertent ingestion exposure than oral exposure. As a control measure, workplace interventions in which workers are educated about the perioral area and inadvertent ingestion exposure, and are encouraged to wash the perioral area may be beneficial.

### Hand-to-Mouth Contact

Time spent "between tasks" was strongly associated with an increased frequency of hand-to-mouth contact (Tables 4 and 6). This is probably related to hand busyness as the hands are generally not engaged while workers are "between" tasks.[17,18] However, the contact frequency during "desk and paperwork" was significantly lower than "between task," although the hands are not particularly "busy" during either activity. This suggests that mental engagement in activities may also be related to contact frequency. It may also be possible to reduce inadvertent ingestion exposure by limiting the amount of time spent "between" tasks.

It was anticipated that a higher awareness of risk among workers would result in lower mouth contact frequencies, but this was not the case. In fact, at industrial worksites workers with risk perception scored higher than 7 and had higher contact frequencies than workers with lower scores in bivariate analysis, although this was not significant in multivariate analysis (Tables 4 and 6). An increased contact rate among the high-risk perception group may reflect the inadvertent nature of exposure from hand-to-mouth contact. Workers who work with substances that they consider hazardous might not necessarily reduce their hand-to-mouth behavior because they may not be aware that they are exposed by this pathway, or be conscious of this behavior. Training on inadvertent ingestion exposure could help workers to become more mindful of hand-to-mouth contact and may reduce exposure.

In the multivariate analysis, workers who used respirators had slightly higher hand-to-mouth contact rates than those who did not (Table 6), although this was not seen in the bivariate analysis (Table 4) and was not statistically significant. However, there was also evidence that the use of gloves and respirators acted as a barrier to contact. Among workers who used gloves and respirators, contact rates were lower during times when these were worn than when they were not worn (Table 4). In addition to controlling dermal and inhalation exposure, this protective equipment may also reduce inadvertent ingestion exposure.

Hand-to-mouth contact frequency was higher at the industrial facilities than at the research laboratory, although this was not statistically significant in multivariate analysis (Tables 4 and 6). There were strict hygiene requirements at the research facility, including pre-shift showers and changing clothes at the beginning of each shift. Furthermore, paper masks were worn for the majority of the shift at the laboratory.

Nail biters and smokers both had significantly higher contact frequencies than non-nail biters and non-smokers (Tables 4 and 6). None of these workers bit their nails during the observation periods and only two contacts with cigarettes were recorded; these were recorded as object-to-mouth contacts (smoking was prohibited on seven of the eight worksites). Moreover, there was no indication that smoking and nail biting were correlated; in fact, nail biting was less prevalent among smokers (11%) than among non-smokers (34%). This indicates that people who either smoke or bite their nails may have higher rates of contact with the mouth even during times when they are not smoking or biting their nails. This information could help to screen individuals who may be at particular risk of inadvertent ingestion exposure.

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Object-to-Mouth Contact

There were a number of differences between the determinants of object- and hand-to-mouth contact, and many of these may be related to respirator use. Respirators were the objects most frequently involved in contact (Table 3). All of the contacts involving respirators were with the perioral area. Simply wearing a respirator was not recorded as a contact, but a contact was recorded if the respirator was rested on the perioral area while talking, if it brushed against the perioral area while being taken on or off, or if it was worn in an incorrect manner that resulted in significant contact between the respirator and the perioral area. This led to one of the most notable differences between hand- and object-to-mouth contact frequency. The frequency of hand-to-mouth contacts was significantly lower during times when workers were using respirators (Tables 4 and 6); but, due to respirator-to-mouth contacts, the frequency of object-to-mouth contacts was significantly higher during this time (Tables 5 and 6). The higher object-to-mouth contact frequency that was seen at the research facility relative to the industrial facilities (Tables 5 and 6) may also be due to respirator-to-mouth contacts. Workers at the research facility wore paper masks while working. These did not always fit properly and were frequently rested on the chins and lips while talking. Although these masks were not respirators, they were treated as respirators in analysis, as they were masks that covered the perioral area. Respirator use may also be related to the diminished relationship between task category and object-to-mouth contact (Tables 5 and 6). In general, respirators were not used when workers were "between tasks" and the frequency of object-to-mouth contacts were not significantly higher during this time than during other tasks (Tables 5 and 6). Although there were insufficient data to examine differences between respirator types in the current study, this should be investigated in future work. For example, full-face masks may be more difficult to rest on the chin and lips, and may be less likely than other respirator types to be associated with increased rates of object-to-mouth contact.

## CONCLUSIONS

This study was carried out as part of a project to develop a predictive exposure model for estimating occupational inadvertent ingestion.[2] The study aimed to gather information on the determinants of hand- and object-to-mouth behavior. Several potentially important determinants were identified, including time spent "between" work tasks, PPE use, smoking and nail biting. The effect of the determinants differed between hand- and object-to-mouth contact, suggesting that these should be considered separately. The majority of the observed contacts involved hands or objects coming into contact with the perioral area rather than the oral cavity. It could, therefore, be possible to use perioral exposure as a surrogate for inadvertent ingestion when measuring exposure. The identified determinants may also enable the development and evaluation of exposure control strategies, for example, the use of PPE and limiting the amount of time that workers spend "between" tasks. This study has contributed to a greater understanding of hand- and object-to-mouth behavior among adults. The findings could be useful in the development of a predictive exposure model and may also have implications for exposure measurement and control.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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