The Short-term Protective Effects of ‘Non-PPE’ Gloves Used by Greenhouse Workers

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ABSTRACT
Task-based worker exposure assessments are used in regulatory product approval for pesticides. Some agricultural workers may be exposed to pesticide residues predominantly via transfer to the hands during plant tending or crop harvesting. They may use thin ‘splash-resistant single-use’ (SRSU) gloves or cotton gloves as good industry practice, for example, to protect a delicate crop from bruising, rather than specifically for chemical protection. These ‘non-personal protective equipment (PPE)’ gloves may or may not have been tested for chemical resistance, but can nevertheless give limited protection from chemicals. This paper reports experiments to assess the protection factors (PFs) of ‘non-PPE’ gloves against chemicals, to better inform the regulatory exposure assessments.

One type of lightweight cotton and three types of 0.1 mm SRSU gloves 25 cm long (latex, nitrile, and vinyl) that might be used as ‘non-PPE’ gloves and one type of 0.4 mm PPE nitrile gauntlet 33 cm long were worn by 36 volunteers in greenhouses at four nurseries, handling plants sprayed with transferable but non-permeating strontium acetate in four consecutive 1-h sessions, including one session in which no gloves were worn. Dislodgeable foliar residues were measured by rinsing leaves in bags. Each subject carried out their task such as weeding or trimming, for their four sessions on their set of plants. Handwashes followed each session, and the washings were sampled and analysed for strontium. Unprotected hand contamination was taken to be the within-subject ‘challenge’ in the absence of gloves. It ranged from 166 to 4091 µg equivalent of strontium acetate on the hands and increased with increasing foliar residues. Geometric mean PFs were 60 (95% CI 38–87, n = 22) for PPE gauntlets, 32 (25–41, n = 65) for SRSU gloves and 5.3 (3.5–8, n = 21) for lightweight cotton. The PFs offered by the waterproof gloves (gauntlets and SRSU) increased with challenge, but for the absorbent cotton gloves it decreased. The measurement of protection is restricted by the limit of quantification (LOQ) such that protection must apparently increase with challenge, nevertheless the above trends remained even after removal of data <LOQ. For the waterproof gloves, protection was similar for dry and wet tasks. For cotton gloves, protection was lower for wet tasks, although this might have been consistent with that decreasing trend, because the ungloved hand challenges were higher for wet tasks than dry.

Default PF values for cotton and SRSU non-PPE gloves may be taken for regulatory exposure assessments from lower quantiles of the distributions of PF results, being 1.3 and 7–10 respectively. The lower quantiles for cotton gloves are close to one, indicating no protection at all.

KEYWORDS: agriculture; exposure assessment; gloves; handwash; pesticide residues; protection factor; surface transfer
INTRODUCTION

Personal protective equipment (PPE), including gloves, can be used as a risk mitigation measure for operators applying pesticides and, if necessary to reduce exposure to acceptable levels, will be specified as a condition of approval on the product label. Individuals re-entering treated crops to perform activities such as crop inspection and maintenance, harvesting and post-harvest handling, may be exposed to foliar residues, but for this group the use of chemical protective PPE gloves is generally not considered a necessary risk mitigation measure. ‘Non-PPE gloves’ in the context of this paper are those gloves worn by workers re-entering treated crops for which the primary purpose is not chemical protection from pesticide residues. Thin cotton gloves, fabric ‘gardening’ gloves, or thin rubber or plastic disposable gloves may be worn by workers as good practice irrespective of pesticide use to protect a delicate crop from bruising (e.g. strawberry harvesting), as a food hygiene precaution or as mechanical protection when pruning. The term ‘thin disposable’ does not describe them well because all gloves should be considered disposable. There is no accepted acronym, so ‘splash-resistant single-use’ (SRSU) is coined here, applying to all single-use gloves of various waterproof materials, e.g. nitrile, latex, polyvinyl chloride (PVC or vinyl), neoprene, and even to polyethylene although pesticides are known to permeate quickly through those (Nielsen, 2005). PPE gloves too are waterproof but are certification tested for chemical penetration and/or permeation. An unpublished 2012 survey by the Horticultural Development Company (HDC) of the types of gloves used in certain agricultural sectors in situations where they would be deemed ‘non-PPE’ was shared with the UK Health and Safety Executive. Light cotton or fabric gloves were mainly used in cucumber production and harvesting; leather or nitrile SRSU gloves were mainly used in carrot production and harvesting; latex or vinyl (PVC) SRSU gloves were used in daffodil harvesting; and latex SRSU gloves were mainly used for potting and handling ornamental Choisya ternata.

Gloves used as non-PPE gloves may or may not be tested to a performance standard for resistance to chemicals. Nevertheless, they may afford some degree of chemical protection, and it is necessary to understand the potential of non-PPE gloves to reduce hand exposure for quantitative exposure assessments. This paper reports experiments to assess the protective effects against chemicals of both PPE and ‘non-PPE’ gloves to better inform the exposure assessments used during regulatory product approval.

In the absence of specific data, the predicted exposures used in those assessments may be reduced by a default ‘protection factor’ (PF) for the gloves. The PF is the ratio of the exposure in the absence of protection to the exposure with protection in place. These default factors are intended to reflect the ‘reasonable worst case’ rather than common use and practice, to incorporate a margin for safety. When sufficient data are available, a suitable factor may instead be selected from a suitable quantile of the data. The use of the term ‘PF’ here does not imply that gloves necessarily give chemical protection. A PF of less than one would indicate an increase in exposure compared to not using them.

The protection offered by gloves may vary depending on the dermal exposure pathway. Three ‘standard’ pathways of dermal exposure are generally accepted by occupational hygienists, arising from the conceptual model for dermal exposure (Schneider et al., 1999): ‘deposition’ from the air as a spray or dust, ‘direct contact’ with a source such as immersion, or ‘surface transfer’ to the skin through touching contaminated surfaces or objects. A simple task such as brush painting may involve all three pathways, whereas agricultural work post-application is entirely through ‘surface transfer’ in the absence of resuspension. Multiple pathways are often involved in a day’s tasks and little pathway-specific data are available.

Wet or dry working could be an exposure modifying factor. Although residues are normally regarded as dried onto the plants, re-wetting with rain or dew can re-mobilize them. Zweig et al. (1984) noted greater hand contamination when strawberry pickers wearing light cotton gloves handled dew-wet plants than when the plants dried later in the same day.

Exposure may be caused by behaviour, e.g. touching items when temporarily not wearing the gloves or inadequate glove donning and doffing procedures. Hand contamination may arise from cuts in glove material or from liquid running down inside the cuffs. Fabric gloves could allow contamination to penetrate through the material, perhaps depending on particle size or liquid viscosity, whereas waterproof gloves
could allow permeation through the intact glove material.

Time-related exposure effects were noted by Kromhout et al. (2004). The broad assumption that contamination builds on the skin at a constant rate during a task is questionable, especially when tasks are event-based rather than continuous, but is often made for the purposes of modelling exposure. It may be a more valid assumption for the more unidirectional ‘deposition’ pathway (e.g. spraying activities), than for the bidirectional ‘surface transfer’ pathway.

The level of challenge may affect the protection that gloves offer. A waterproof-gloved hand plunged partway into a liquid bath has almost infinite protection in theory, whereas protection against a light dusting on a surface will depend much more on behaviour when removing the gloves.

**Previous studies**

A number of intervention studies have included addition of gloves, but often as part of a wider study to seek a reduction in exposure, and the effect of gloves was rarely isolated. Biological monitoring (BM) has been used as a means of assessing the protective effect of gloves from the internal dose, and it also includes all other factors affecting uptake. Other studies have measured gloved hand exposure from over- or underglove dosimeter residues, or hand residues beneath gloves, but few studies have measured hand exposure both with and without gloves. Individual subject data were often not published to obtain individuals’ protection, but estimates based on averaged exposure values may be made.

Methodologies for assessing exposure of the skin contaminant layer beneath a protective glove after glove removal are by handwashing or handwiping (measurement by removal), or recovering an absorptive under-glove dosimeter (measurement by interception). In some cases, handwashing or handwiping may give low removal efficiencies of lipophilic pesticides (Brouwer et al., 2000a), and the method is sometimes not suitable for field studies. Major differences between the three methods were observed (Fenske et al., 1999). Absorptive gloves outside protective gloves or on unprotected hands can retain substantially more than the unprotected hands themselves (Brouwer et al., 2000b; Gorman Ng et al., 2013). Nevertheless, if the same methodology is used both with and without gloves, low recovery efficiency (undersampling) or excessive collection efficiency (oversampling) may cancel out in the calculation of PF, provided those efficiencies do not vary with the level of hand contamination.

Maddy et al. (1989) found an average of 2 to 3% of exposure to captan with light cotton gloves in strawberry pickers compared to without gloves—a PF of 33 to 50. Fenske et al. (1989) measured captan in handwashes of eight subjects after harvesting peaches. One hand was bare and one wore a light cotton glove. Bare hands exhibited a linear trend of accumulation from $1/2$ to $3\text{ h}$, whereas hands beneath cotton gloves accumulated less in the first $1/2\text{ h}$ than in subsequent periods. The cotton gloves were also being used as dosimeters, and accumulated more in the first $1/2\text{ h}$ than subsequently. The gloved hands’ exposures were in a similar range to the ungloved. A PF at or close to 1 may be inferred from their data for the light cotton glove for the ‘surface transfer’ pathway, i.e. no protection at all. Fenske observed that ‘the cotton gloves used in this study cannot be considered protective, since exposure to gloved hands can actually exceed bare hands’.

Brouwer et al. (2000b) measured propoxur in handwashings of 18 carnation harvesters in two successive trials, using nitrile SRSU gloves and whole-body protective clothing (5–299 μg), and using neither (7–1523 μg), and thus found a median PF of ~20 during the task for the ‘surface transfer’ pathway. Data were very strongly skewed which may indicate many results near to the limit of quantification (LOQ). However the less skewed BM data indicated an overall PF of only two. The reduction in metabolites cannot be attributed solely to glove use because whole-body protective clothing was also worn. Part of this difference in PFs inevitably arises from simultaneous use of both methods whereby a large mass is soon removed from the hands, reducing subsequent uptake for BM. Behaviour not related to the task can also affect BM data, through further transfer to the skin after the handwashing process, from sleeves or surfaces and by hand to mouth uptake.

Bradman et al. (2008) used 15 strawberry harvesters as a control group and 29 as an intervention group, all exposed to malathion residues by the ‘surface transfer’ pathway. The intervention supplied protective coveralls, SRSU nitrile gloves, and an education programme raising awareness of transfer hazards and
hand and glove hygiene. Six of the control group also wore gloves. Median PFs of 97 by handwashing and 5.7 from urinary BM may be inferred. The BM could have been greatly affected by strawberry eating, which appeared to dominate uptake. Other simultaneous intervention factors, such as sleeved work clothing and the education program may have influenced those results, and they cannot be relied upon as an estimate of the PF of gloves only.

**METHODS**

**Gloves**

Five types of non-powdered glove were selected for this study from the generic types found in the HDC survey, four of which could be considered non-PPE gloves. They were: (i) Knitted stockinette cotton (Arco Men’s and Women’s, one size each, pre-washed to remove soluble strontium), (ii) Polyco Bodyguards\(^4\) latex 250 mm SRSU in four sizes, (iii) Top Glove nitrile 250 mm SRSU in four sizes, (iv) Top Glove vinyl 250 mm SRSU in four sizes, and (v) Ansell Edmont 37-65S 0.38 mm unlined nitrile 330 mm gauntlets (sizes 8–11), occasionally replaced with lined gauntlets for smallest hands (37–675 size 7). The last-mentioned, considered a PPE glove, had been labelled as certification tested for penetration and permeation, but none of the SRSU gloves were similarly labelled. The latex SRSU gloves were unpowdered and low protein in case of allergic reaction whereas those commonly used at nurseries were neither.

**Participants**

Ornamentals nurseries were recruited in autumn 2012 by a subcontractor (Dove Associates) with industry contacts. Nurseries were asked to reserve sufficient plants to ensure that each individual carried out exactly the same handling task for 4 h on exactly the same species and variety. A minimum working time of 1 h was selected. A total of 36 volunteer subjects (19 males and 17 females, but 4 short of the total required) were recruited from four nurseries. A fifth nursery was found late in the year but they reported that leaves had already fallen, so the opportunity was taken to carry out a blank test spraying deionized water. Health and Safety Laboratory staff volunteered for the handwash recovery studies. These human volunteer studies were conducted with the approval of the University of Sheffield Research Ethics Committee.

**Experimental design**

To measure protection, it was important that test conditions and sampling methodology were consistent when monitoring both with and without gloves. It was thought better to use the same subject for the same task, challenge, and exposure time. Conditions could change from day to day, so a within-day task was preferred. The plants were arranged by variety in ‘sets’ of bays in the greenhouses. Each subject was allotted a task and a ‘set’ for the whole day. They performed four successive 1-h ‘sessions’, wearing three types of glove and no gloves for one session each. A balanced, incomplete block, first-order carry-over experimental design was used to ensure that each glove type was tested an equal number of times, and each followed all the others equally often. Any behavioural effects of carry-over from any particular glove type should therefore even out. The first incomplete block of 10 subjects was formed from each permutation of three from five. A fourth (no-glove) column was added, and then each row shuffled to spread gloves across rows evenly. The full design required 40 subjects to balance (160 sessions), and was created from 4 blocks of 10 by exchanging columns. A spreadsheet was used to randomize the assignment of gloves, columns, and within-block rows. The assignment of gloves to sessions is shown in Table 2 alongside the results. The dependency of PF on challenge was analysed using SPSS v14 (SPSS Inc).

**Surrogate pesticide**

Strontium acetate hemihydrate was selected as a surrogate chemical for pesticides because it is easily detected in solution at very low concentrations, has low toxicity to plants, and is highly water soluble, making it highly transferable to and efficiently washed from the skin. The literature on washing efficiency is scanty. *Ilyin et al.* (1975) claimed 99.9% removal of radioactive strontium chloride \(^{85}\)SrCl\(_2\) from volunteers’ skin after 6 h with their decontaminant solution of a highly oxidized 5% carboxymethyl cellulose in an unnamed solvent and 5% sodium bicarbonate. They found 0.25% dermal uptake over 6 h from intact skin but 57% over areas scratched with a grater. The washing protocol was unspecified. *Wahlberg (1965, 1968)*
measured 2% absorption of radioactive $^{89}\text{SrCl}_2$ solution through guinea pig skin from 5 h contact, which did not vary over a range of applied concentrations. However, the contact area was small (3 cm$^2$) and the strontium component appeared to be absorbed at a high area rate (14 µg cm$^{-2}$ h$^{-1}$).

There is a little environmental strontium background in soil. The permeation of strontium acetate through waterproof gloves has not been tested to the author’s knowledge. Mäkelä and Jolanki (2005) state that ionic molecules that do not degrade the glove material are not likely to permeate. Manufacturer’s data for the nitrile PPE gauntlets (Ansell Healthcare, 2008) shows permeation resistance of >6 h for the more aggressive glacial acetic acid, citric acid, and electroplating salts. A mixture of strontium acetate and Tinopal CBS-X® was sprayed onto the plants in the previous afternoon. The overnight irrigation was turned off to dry it to residue (with the exception of cuttings that remained wet). Tinopal CBS-X® is a water-soluble colourless fluorescent dye that stains the hands on contact. It was used to record the locations of hand contact after the first exercise only, by photographing hands inside a long-wave ultraviolet light box.

Handwashing method
Hand exposure was measured by ‘bagwashing’ both hands in a fresh polyethylene bag containing 250 ml of warm deionized water handwashing solution, with 0.5% w/w citric acid acting as a chelating agent (Esswein et al., 2011) and acidifying the mixture to encourage removal of metal ions. Subjects followed a written procedure with pictograms, to wash only up to the base of the hand and thus ensure that contamination beyond the glove’s protective cuff area was not included. Those with sleeves pulled them up to keep them clear of the washing water. After handwashing, each subject dipped a clean 50 ml container into the shaken bag to subsample it. Second handwashes, where taken, used a fresh bag of solution. The subsamples were submitted for analysis by inductively coupled plasma atomic emission spectroscopy to quantify the strontium ion. Blank handwashing solution and known spikes of strontium acetate solution were also submitted.

Before the first session, pre-exercise handwashes removed soluble strontium arising from environmental sources during everyday activities. Subjects were not supervised closely during the study sessions to avoid influencing behaviour. At the end of each session, they returned to the wash station and removed their own gloves in their own way before washing their hands once as above. Second handwashes after no-glove sessions were instituted following the second field visit. Interim handwashes were taken before mid-session toilet breaks, and the masses summed with their end-of-session handwashes. Coffee and lunch breaks were accommodated between sessions. Additional pre-exercise handwashes after all breaks removed inadvertent strontium exposure during those breaks.

Handwashing study
Handwash removal efficiency was measured on nine volunteer staff at the Health and Safety Laboratory by dosing (non-radioactive) strontium acetate solutions. 250 µg or 2500 µg were dosed in two 100 µl aliquots, one onto each pre-washed hand and spread by rubbing both hands together while wet. They were dried first with a hairdryer to prevent dripping of excess liquid, then by the heat of the hands for ~3 min with occasional rubbing but without touching anything else, a total of ~5 min residence time before two successive bagwashes. At both doses, handwash removal efficiencies were 89 ± 10% of the original dose for a single handwash and a further 7 ± 3% for the second, combining to 96 ± 8% for two successive handwashes (Supplementary Fig. S1 online). Spiked doses directly into the bag yielded results close to 100%. Doses of 42 µg in 100 µl were left for 10 min residence with hands clasped without using the hairdryer. Removal was 99 ± 14% of the applied dose for the first wash and 109 ± 12% for two successive washes combined. Overall handwash removal efficiency was therefore assumed to be 89 and 96% for all doses, to prevent overestimating hand protection at the lowest doses.

Absorption and retention on the hands were assessed in four further volunteers, dosed with single 120 µl aliquots containing 150 or 1500 µg. They placed their hands inside two plastic bags for 1 h to prevent accidental losses through contact, before bagwashing inside those two bags successively. The amounts recovered from the hands and bags combined (Supplementary Fig. S1 online) were in a similar percentage recovery range to the short-term studies, indicating no significant combination of
absorption and retention over the hour compared to a few minutes. A control volunteer’s handwash (0 µg dose) was <LOQ which indicated that no significant strontium exuded from the hands in the hour. It is acknowledged that this mimics absorption of wet residue rather than dried residue, but the crops handled were indeed sometimes wet, and the hands inside the gloves became wet with perspiration in the study.

Background strontium in gloves
The insides of individual waterproof gloves were rinsed with 125 ml of handwashing solution. Pairs of cotton gloves were rinsed in 250 ml. No detectable soluble strontium was found as background in the SRSU nitrile, SRSU vinyl gloves or the men’s cotton gloves (LOQ equivalent to 5.9 µg of strontium acetate). An insignificant remnant was found in the two pre-washed women’s cotton glove blanks (1.7 µg above LOQ), a small amount in the latex gloves (4.1 µg above LOQ), but a significant amount in the gauntlets (30 ± 6 µg above LOQ).

Dislodgeable foliar residues
The protection offered by gloves was suspected to depend upon the level of potential exposure, which is influenced by dislodgeable foliar residue (DFR) and individual behaviour. The liquid concentration of tracers sprayed onto the plants was varied between the nurseries to create a range of DFRs (Table 1). DFR also depends on leaf size, plant height, and area application rate. DFR was measured by stratified sampling of top, middle, and bottom leaves into a polythene bag, three or four samples being taken from worked areas in each individual’s ‘set’ as the day progressed. The leaves were bag-washed in 100 ml of solution, and one-sided leaf areas measured photographically using Adobe Photoshop Elements 8®. Soil content was not monitored.

RESULTS

Tasks, DFR, and post-session handwashes
Table 1 summarizes the plants, tasks, subjects involved, and the DFRs. Each subject carried out their allotted task on their allotted ‘set’ of plants for four consecutive 1-h sessions, taking breaks between some sessions to replicate their normal work pattern as shown in Table 2. Tasks carried out were: weeding pots, involving damp soil contact rather than dry foliage; pruning and trimming of leaves with secateurs or shears, the latter involving little direct contact with foliage; tying up trailing shoots onto canes and trimming with secateurs; and potting of prepared (wet) cuttings. Most of the trimming tasks were on dry plants, but some were heavily wet with morning dew. One subject reported removing and re-donning the same pair of nitrile SRSU, and three donned fresh pairs within the hour. Only one subject reported removing the gauntlets at any time, although more may have done so. Four vinyl gloves had split fingertips at removal, all known to the subjects but not changed.

Table 2 summarizes the 164 single handwashing and 36 double handwashing results from the field study corrected for handwash removal efficiencies as appropriate. The subjects’ hands were not found to be abraded before or after the exercises so no significant absorption was considered to have taken place. The contamination that the subjects received in the ‘no-gloves’ sessions correlated with the DFR (Supplementary Fig. S2 online, Pearson $r = 0.37$, $P = 0.025$ excluding the blanks).

Pre-exercise contamination
Pre-exercise washes represent the amount of soluble strontium on the hands from environmental sources during everyday activities. They were more log-normally than normally distributed (Supplementary Fig. S3 online), with geometric mean (GM) of 10.9 µg of strontium acetate equivalent and geometric standard deviation (GSD) = 1.5.

Blank nursery
Post-session handwashes at the fifth (unsprayed) nursery closely matched the amounts found as backgrounds in gloves, with ‘no gloves’ matching the pre-exercise washes (Table 2). Glove background (if any) was therefore subtracted from all post-session handwashing results from Table 2 at the four sprayed nurseries. Results <LOQ were set to the LOQ. This had no substantial effect on the calculation of protection offered by the gloves, apart from the gauntlets.

Carry-over effects
Most subjects carried out a second handwash after the fourth session. Where the first handwash was <160 µg, insignificant amounts were found in second handwashes. Where >160 µg ($n = 16$), second handwashes
Table 1. Plant varieties, subjects, and dislodgeable residues.

| Nursery | Plant variety                  | Task                        | Set  | Subjects         | Approx. Spray Concentration g l\(^{-1}\) | Comments                      | Ave. DFR µg cm\(^{-2}\) |
|---------|--------------------------------|-----------------------------|------|------------------|------------------------------------------|-------------------------------|--------------------------|
| 1       | Euonymous Emerald Gaiety       | Hand weeding                | 1    | 1,3              | 10                                       | Dry                          | 5.1                      |
| 1       | Euonymous Emerald Gold         | Hand weeding                | 2    | 2,4              | 10                                       | Dry                          | 3.8                      |
| 1       | Photinia Red Robin             | Pruning                     | 3    | 5,6              | 10                                       | 2 samples dry, 1 rainwater wet | 5.0                      |
| 2       | Coreopsis Calypso              | Pruning                     | 4    | 8,9,10,12,15     | 8.4                                      | Dry                          | 1.6                      |
| 2       | Hebe Magic Summer              | Pruning                     | 5    | 7,11,13,14       | 8.4                                      | Dry                          | 3.5                      |
| 3       | Pyracantha                      | Pot cuttings                | 6    | 20,22,23,24,25,26,27,28 | 5.2                                      | Kept wet with spray          | 7.2                      |
| 3       | Hedera Goldenchild             | Tying up and trimming       | 7    | 19,21            | 5.2                                      | Very wet with dew/mist       | 9.9                      |
| 3       | Hedera Sagittofolia             | Tying up and trimming       | 8    | 16,17            | 5.2                                      | Very wet with dew/mist       | 7.4                      |
| 3       | Hedera Lutzik                   | Tying up and trimming       | 9    | 18               | 5.2                                      | Very wet with dew/mist       | 3.6                      |
| 4       | Euonymous Emerald Gold 75%     | Pruning 10 and 11\(^{a}\)   | 10   | 33,34            | 3                                        | Dry                          | 7.0                      |
| 4       | Photinia 25%\(^{a}\)           |                             | 11   | 33,34            | 3                                        | Dry                          | 8.4                      |
| 4       | Aucuba                          | Pruning                     | 12   | 35,36            | 3                                        | Dry, but beads of moisture in bases of leaves | 3.2                      |
| 4       | Clematis                        | Tying up and trimming       | 13   | 29,30,31,32      | 5.2                                      | Dry                          | 6.9                      |
| 5 Blank | Clematis Wesselton             | Tying up and trimming       | 14   | 37,39            | 0                                        | Dry                          | 0.14                     |
| 5 Blank | Clematis Broughton-on-Bridge    | Tying up and trimming       | 15   | 38               | 0                                        | Dry                          | 0.02                     |
| 5 Blank | Clematis Montessa and B-on-B   | Tying up and trimming       | 16   | 40               | 0                                        | Dry                          | 0.02                     |

\(^{a}\) Insufficient plants in a set for 4 h, so two sets were worked for 75 and 25\% of the time in each session.
Table 2. Recoveries of soluble strontium from handwashes, expressed as µg of strontium acetate hemihydrate. Glove types are indicated for each session.

| Subject | Session 1 | Session 2 | Session 3 | Session 4 |
|---------|-----------|-----------|-----------|-----------|
| 1       | P         | 28 v      | 28 l B    | 490 N     | 65 g      |
| 2       | P         | 90 c B    | 691 N     | 68 a l B  | 70 v      |
| 3       | P         | 691 N     | 36 a g B  | 25 l      | 21 n      |
| 4       | P         | 642 N     | 57 a c B  | 39 v      | 34 g      |
| 5       | P         | 52 g      | 58 v B    | 39 n B    | 242 N     |
| 6       | P         | 38 c      | 10 v B    | 207 N B   | 15 n      |
| 7       | P         | 21 n      | 38 l B    | 1811 N    | 56 a v    |
| 8       | P         | 517 N     | 21 n B    | 28 g      | 29 c      |
| 9       | P         | 22 l      | 17 c B    | 20 g      | 328 N     |
| 10      | P 6.9 n   | 166 N B   | 15 c      | 19 l      |
| 11      | P 9.0 v   | 2487 N B  | 38 l      | 29 v      |
| 12      | P 6.9 n   | 16 l B    | 363 N     | 68 a c    |
| 13      | P 6.9 l   | 45 g      | 1138 N    |
| 14      | P 57 g    | 23 v B    | 126 c     | 1418 N    |
| 15      | P 769 N   | 22 n B    | 23 v      | 50 g      |
| 16      | P 108 n   | 3371 N B  | 215 v     | 634 c     |
| 17      | P 47 v    | 1375 N B  | 65 l      | 50 n      |
| 18      | P 278 c   | 46 a g B  | 15 n      | 1127 N    |
| 19      | P 2409 N  | 218 a g B | 575 c     | 71 a l    |
| 20      | P 12 l    | 482 c B   | 1048 N    | 59 a n    |
| 21      | P 820 N   | 130 a v B | 107 g     | 82 l      |
| 22      | P 20 l    | 765 c B   | 155 v     | 1070 N    |
| 23      | P 9.0 l   | 1329 N B  | 55 n      | 66 g      |
| 24      | P 50 v    | 1518 N B  | 79 g      | 342 c     |
| 25      | P 14 n    | 46 g B    | 1880 N    | 169 a v   |
| 26      | P 646 N B | 485 c B   | 34 n      | 48 v      |
| 27      | P 1498 N  | 82 a n B  | 31 v      | 28 l      |
| 28      | P 32 g    | 867 N B   | 314 c     | 19 n      |
| 29      | P 16 g    | 44 l B    | 1201 N    | 946 c     |
| 30      | P 3240 c  | 357 a n B | 105 l     | 4091 N    |
| 31      | P 57 l    | 6.9 g B   | 63 v      | 4027 N    |
yielded 7 ± 5% of the first (Supplementary Fig. S4 online). This was consistent with the handwashing study where second handwashes were 8% of the first. The results of 13 sessions were deemed to be at risk of carry-over effects if a single (89% efficient) handwash in the previous session yielded a high result (>200 µg). Those at risk were mainly in the earlier part of the study before double handwashes were instituted after no-glove sessions. Some cotton glove handwashes were almost as high as the no-glove washes and a few results of those sessions were among those at risk. Those 13 results were adjusted for carry-over by subtracting 7% of the previous exercise’s result. Results <LOQ were set to the LOQ.

The handwash efficiency corrected results from Table 2 were corrected for glove background and adjusted for carry-over as above and are shown in Supplementary Table S1 online. The challenge contamination (the mass on both hands when wearing no gloves), ranged from 166 to 4090 µg, and was used to calculate PFs for the three gloved sessions within-subject.

The PFs of the gloves form acceptably log-normal distributions (Supplementary Fig. S5 online). (KS Z score = 0.64, 0.42, and 0.42 for all SRSU combined, cotton, and gauntlets respectively). The non-parametric quantiles of the distributions are given in Table 3. Those quantiles were compared with their equivalents when glove backgrounds were not subtracted or not adjusted for carry-over (Supplementary Fig. S6 online). No effect was seen up to 90th percentile for cotton or SRSU gloves. However for PPE gauntlets, subtracting the high background strontium in the gloves increased PF by ~5.

**Statistical analysis of dependency on challenge**

The gloved hands’ background corrected and carry-over adjusted contamination results are plotted against the no-glove hand contamination in Fig. 1a. The PFs are shown in Fig. 1b. The results were analysed using SPSS v14 (SPSS Inc) as a general linear model (GLM) analysis of variance (ANOVA) using Log10(PF) as the dependent variable, the five glove types as a random factor, and Log10(No-glove contamination) as a covariate. This is an analytical representation of the plotted data and regression lines of Fig. 1b. Bonferroni post hoc tests showed that the three types of SRSU gloves (nitrile, latex, and vinyl) could not be distinguished at \( P = 0.05 \), and therefore their data were pooled as a subgroup. The GLM ANOVA statistical output for three

| Subject | Session 1 | Session 2 | Session 3 | Session 4 |
|---------|-----------|-----------|-----------|-----------|
| 32      | P         | 2824 N    | 217 v     | 623 c     | 386 l     |
| 33      | P         | 46 g      | 23 n      | 364 N     | 36 l      |
| 34      | P         | 17 c      | 44 g      | 182 N     | 20 v      |
| 35      | P         | 62 v      | 1234 N    | 65 g      | 74 n      |
| 36      | P         | 15 v      | 14 n      | 63 c      | 191 N     |

Blank Nursery 5

| Subject | Session 1 | Session 2 | Session 3 | Session 4 |
|---------|-----------|-----------|-----------|-----------|
| 37      | P         | 10 l      | 6.9 v     | 6.9 n     | 24 N      |
| 38      | P         | 6.9 n     | 6.9 c     | 9.7 N     | 30 g      |
| 39      | P         | 6.9 c     | 12 N      | 6.9 l     | 29 g      |
| 40      | P         | 14 N      | 10 l      | 6.9 n     | 17 c      |

Key: normal typeface = single handwash at end of session, efficiency corrected at 89%. Italic typeface = two successive handwashes at end of session, summed and efficiency corrected at 96%. Bold typeface = result <LOQ.

B = break between sessions, always followed by a before-session prewash; P = prewash before the first session, used to monitor soluble strontium arising from the environment; v = vinyl SRSU gloves; l = latex SRSU gloves; n = nitrile SRSU gloves; g = nitrile PPE gauntlets; c = cotton gloves; N = no gloves worn.

*Result deemed at high risk of significant carry-over from previous session.
glove types (cotton, SRSU, and gauntlets) is given in Table 4. This was used as a basic model for extra statistical tests for any effects of session order, gender, carry-over, or wet/dry tasks (not significant, outputs not shown). They confirmed that the basic model was suitable without such extra factors, that PF was significantly affected by the glove type (main effect) and the level of unprotected contamination (main effect), and that the level of contamination affected PF differently for the different glove types (interaction term).

There was slightly higher gloved and ungloved hand contamination for wet tasks than for dry (data not shown), which cancelled out when calculating PFs for all waterproof (i.e. PPE and all SRSU) gloves. For cotton gloves, however, there remained slightly lower PFs for wet tasks than for dry, but the downward trend of the PF linear regression line for cotton gloves shown in Fig. 1b, accounts for this within the basic model (also Supplementary Fig. S7 online). Therefore wet and dry conditions and hand contamination are confounded for cotton gloves.

## DISCUSSION

### Hand contamination

For PPE gauntlets, there was no change in hand contamination over the range of challenge (non-significant linear regression $P = 0.9$, Fig. 1a). This may be because the results $<\text{LOQ}$ were found at all challenge levels. For SRSU gloves, there was a significant increase in hand contamination with challenge (linear regression $P \leq 0.05$). There was slightly higher average hand contamination using vinyl SRSU than using latex or nitrile SRSU, which might be accounted for by split vinyl glove fingertips. For cotton gloves, there was a highly significant increase with challenge, exceeding the 1:1 slope shown by the plot of ‘no-gloves’ contamination against itself. In other words, there was more

### Table 3. Quantiles of the distributions of the corrected, adjusted protection factors by glove type.

|          | Gauntlet | Cotton | All SRSU\(^a\) | Vinyl SRSU | Latex SRSU | Nitrile SRSU |
|----------|----------|--------|----------------|------------|------------|--------------|
| N        | 22       | 21     | 65             | 23         | 21         | 21           |
| $n < \text{LOQ}$ (% of N) | 9 (41%) | 0 (0%) | 8 (12%)        | 1 (4%)     | 3 (14%)    | 4 (19%)      |
| GM       | 60.1     | 5.3    | 32.1           | 23.4       | 40.0       | 36.5         |
| GSD      | 3.0      | 2.8    | 2.6            | 2.5        | 2.5        | 2.6          |
| GM 95% CI upper | 94.4 | 7.6    | 40.8           | 33.3       | 57.0       | 55.1         |
| GM 95% CI lower | 44.2 | 3.5    | 24.9           | 15.8       | 26.0       | 25.4         |

| Percentiles |          |        |                |            |            |              |
|-------------|----------|--------|----------------|------------|------------|--------------|
| 5           | 10.8     | 1.3    | 7.1            | 4.6        | 7.7        | 6.8          |
| 10          | 12.0     | 1.3    | 10.4           | 7.7        | 10.9       | 14           |
| 25          | 29.0     | 2.5    | 15.6           | 12.6       | 20.2       | 18           |
| 50 Median   | 62.8     | 4.5    | 30.5           | 19.9       | 40.9       | 31           |
| 75          | 125\(^b\) | 11.1  | 63.9           | 48         | 76         | 82           |
| 90          | 290\(^b\) | 21    | 152\(^b\)     | 76         | 162\(^b\) | 162\(^b\)    |
| 95          | 543\(^b\) | 55    | 184\(^b\)     | 209\(^b\)  | 190\(^b\) | 211\(^b\)    |

\(^a\)SRSU group is nitrile, vinyl, and latex SRSU gloves combined.

\(^b\)Highest quantile PFs calculated from hand contamination data $<\text{LOQ}$.
increase in hand contamination than the increase in challenge alone could explain. This could imply breakthrough of the absorbent cotton glove, with the glove possibly acting as a reservoir.

**Protection factor**

For gloves, the performance at keeping out a challenge may well depend on the exposure pathway and the behaviour of the user. It is unlikely to be a fixed proportion of challenge as might be found for respirators. For the ‘surface transfer’ pathway, the ‘challenge’ could be deemed to be the leaf surface loading (DFR), but more appropriately it is the user’s dermal contamination in the absence of gloves, which also takes individual behaviour into account. **Figure 1b** shows that the PF increased with challenge contamination for the
waterproof gloves but decreased for the cotton gloves, although the slope of the cotton linear regression was not significantly different from zero ($P = 0.067$, Supplementary Fig. S7 online). Data at (or limited to) the LOQ align at the edge of the shaded area (<LOQ) which is unavailable data space, so the regression lines will inevitably tend to be positive. Nevertheless, the positive trends remained (not shown) even when data <LOQ were excluded. The negative trend was unaffected for cotton gloves because all the results were >LOQ.

The SRSU gloves selected were not labelled as tested for penetration or permeation. The cotton gloves were deliberately selected to be thin and open-weave, and a more closely woven type of fabric glove may well ‘protect’ better than those, at least on first use. Where workers are obliged to provide their own non-PPE gloves, they may well use less physically robust brands of gloves, re-don them and over-extend their lifetimes.

The range of tasks selected involved only the ‘surface transfer’ pathway typical of indoor crop handling tasks with close and continuous contact with treated foliage. Indoor or outdoor harvesting was not itself trialled. Contamination through ‘deposition’ or ‘direct contact’ pathways in other tasks may cause the gloves to offer more or less protection.

The results are all time-constrained to 1 h. The protection offered by a pair of gloves may deteriorate over longer time periods. In theory, the SRSU gloves should be changed for fresh when damaged and at intervals during the day when workers take a ‘glove break’ to help prevent dermatitis and for refreshment. In practice, several volunteers carried on with split gloves, and one re-donned the same pair during the hour. Only one person reported removing and re-donning their PPE gauntlets in these 1-h exercises.

If the gloves remained intact, all the hand exposure could have occurred by handling the removed gloves or by immediate re-contamination from their (presumably contaminated) sleeves before and during donning or doffing. This is taken into account within the spread of results, because some subjects wore long sleeves while some had bare forearms. No account is taken of permeation of waterproof glove materials in this study, which may vary from one pesticide to another.

A remaining uncertainty about the assignment of a default PF to non-PPE gloves is whether an external dose is the best exposure metric to assess it at all. (Cherrie et al., 2004) Studies using BM have yielded PFS averaging as little as two with smaller range. However task, dose and subject are never precisely

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**Table 4. ANOVA output of basic model from SPSS (total N = 108).**

| Source                                    | Type III SSq | df  | MS    | F      | Sig. |
|-------------------------------------------|--------------|-----|-------|--------|------|
| Intercept                                 | Hypothesis   | 0.086 | 1     | 0.086  | 0.102 | 0.779 |
|                                            | Error        | 1.742 | 2.077 | 0.838a |      |      |
| **Main effects**                          |              |      |       |        |      |      |
| $\log_{10}$ (No-glove Contam)            | Hypothesis   | 1.471 | 1     | 1.471  | 10.665 | 0.001 |
|                                            | Error        | 14.074 | 102   | 0.138b |      |      |
| Glove type                                | Hypothesis   | 1.857 | 2     | 0.929  | 6.730 | 0.002 |
|                                            | Error        | 14.074 | 102   | 0.138b |      |      |
| **Interaction**                           |              |      |       |        |      |      |
| Glove type × $\log_{10}$ (No-glove Contam)| Hypothesis   | 3.436 | 2     | 1.718  | 12.451 | 0.000 |
|                                            | Error        | 14.074 | 102   | 0.138b |      |      |

a $MS = 0.886 MS(glove type) + 0.114 MS(error)$.

b $MS = MS(error)$. 

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matched in those studies. It is not possible to carry out BM in parallel with handwashing in a same-day study in a task- and subject-matched trial. BM remains a more appropriate assessment of body uptake from all tasks and all routes, but the ability of gloves to prevent exposure is limited only to that task when they are supposed to be worn, and therefore an external measure of protection is valid for exposure assessment during that task only. The apparently lower PFs obtained from BM studies may well be caused by behavioural factors outside of the ability of gloves to control - perhaps re-contamination with a long residence time after completing the day’s task and/or ingestion. O’Connell et al. (1993) noted, during harvesting operations of grapes, that hand exposures occurred to field workers packing picked grapes in a situation that could not be explained by foliar contact, as they had no such contact, and that some other mechanism than direct transfer from leaves to hands must be contaminating them that they could not identify.

The use of gloves may itself increase uptake. Rawson et al. (2005) found that uptake of rapidly absorbed N-methyl pyrrolidone was 25% higher from 15 min contact time inside dosed, internally contaminated gloves than from the equivalent unprotected hand dosed and left to dry for 15 min. The proportional difference rapidly increased to 300% with the same doses over 30 min. It follows that the protection in terms of external dose offered by a glove may be offset by increased uptake during the working period. Any difference would depend on the rate of uptake of the challenge formulation.

CONCLUSIONS
A suitable value for an assigned PF for regulatory exposure assessments should be taken from the lower quantiles of the distribution of results to allow for limitations of the study. The difference in PF between cotton and SRSU gloves means that it is not realistic to assign the same PF to all ‘non-PPE’ gloves. The lower quantiles for cotton gloves are close to one, confirming ‘no protection at all’ as found by Fenske et al. (1989). The lower quantiles of SRSU gloves indicate PFs of 7–10, and for PPE gauntlets 11–12, although the spread of PFs found in this study cover the spreads found in other studies.

The PFs of reusable (i.e. cotton and PPE) gloves may reduce in the longer-term through re-donning on subsequent days. The PFs of SRSU gloves may also be lower over longer-term use than 1 h. Therefore under a precautionary approach, the PFs given here should be regarded as overestimates rather than underestimates.

The protection was linked to the level of challenge even when results <LOQ were removed, but this work demonstrates that this link is inherent in the calculation of PF when some results are <LOQ.

SUPPLEMENTARY DATA
Supplementary data can be found at http://annhyg.oxfordjournals.org/.

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