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Original Article

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Recall of exposure in UK farmers and pesticide applicators: trends with follow-up time

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Abstract

Background: Occupational epidemiological studies on pesticide use commonly rely on self-reported questionnaire or interview data to assess exposure. Insight into recall accuracy is important, as misclassification of exposures due to imperfect recall can bias risk estimates.

Methods: We assessed the ability of workers in three UK cohorts (Prospective Investigation of Pesticide Applicators' Health [PIPAH], Pesticide Users' Health Study [PUHS], and Study of Health in Agricultural Work [SHAW]) to remember their working history related to pesticide exposure over time periods ranging from 3 to 14 years prior. During 2019–2020, cohort participants were re-surveyed using a similar questionnaire to that used previously. We compared recall of responses at follow-up to those reported at baseline related to crops/areas of work, use of personal protective equipment (PPE) items, hygiene habits, frequency of pesticide use, and application method. To assess the extent of recall, we used sensitivity, specificity, the percentage of overall agreement, and area under the curve (AUC) values. We also examined the presence of over or underestimation of recalled years, and days and hours per year, of working with pesticides using geometric mean ratios (GMR) and regression analysis to investigate any trends based on demographic characteristics.

Results: There were 643 individuals who completed both the baseline and follow-up surveys in the three cohorts with response rates ranging from 17 to 46%. There was a strong correlation (rho = 0.77) between the baseline and recalled years working with pesticides, though higher values were reported at follow-up (GMR = 1.18 [95% confidence interval: 1.07–1.30]) with no consistent differences by demographic characteristics. There was stronger agreement in the recalled days compared to hours per year in two of the cohorts. Recall for a number of exposure determinants across short and

What's Important About This Paper?

Occupational epidemiological studies on pesticide use commonly rely on self-reported data to assess exposure, but there is little evidence to assess the reliability of these reports. This study examined recall ability in three UK cohorts related to pesticide exposure over time periods ranging from 3 to 14 years. Recall was more reliable within a few years, and specifically for those exposure indicators such as crops and hygienic practices, as well as days per year working with pesticides.

longer periods entailed overall agreement of >70%, though with some differences: for example, sensitivity for long-term recall of crops was poor (<43% in PUHS), whereas short-term recall of hygiene practices was good (AUC range = 0.65–1.00 in PIPAH).
Conclusion: Results indicate that recall ability may deteriorate over a longer period. Although low-response rates may require these findings to be interpreted with caution, recall for a number of exposure determinants appeared reliable, such as crops and hygiene practices within 3 years, as well as days per year working with pesticides.

Keywords: bias; exposure misclassification; pesticides; recall; self-report questionnaires

Introduction

Occupational exposure to pesticides, including those in the UK, can be harmful, with studies reporting possible links to, for example, neurological effects (Beach *et al.*, 1996; Pilkington *et al.*, 2001; Povey *et al.*, 2014), non-melanoma skin cancer, testicular cancer, multiple myeloma (Frost *et al.*, 2011), lower bone formation (Compston *et al.*, 1999), DNA damage (Atherton *et al.*, 2009), as well as acute poisoning (Solomon *et al.*, 2007); reviews with other (non-UK) studies also indicate increases with other cancers (e.g. bladder, leukaemia), asthma, diabetes (Kim *et al.*, 2017), and adverse reproductive outcomes (Fucic et al., 2021).

Details of agricultural workers' practices are often collected in epidemiological studies via self-reporting methods. Reporting of past activities is potentially subject to a range of different recall errors, including telescoping (incorrectly shifting an activity forward or backward in time), heaping (incorrectly merging past events into one point in time), and recall decay (forgetting historic events) (Beegle *et al.*, 2012). Furthermore, there may be survey ambiguity or biases relating to under/over-reporting socially unacceptable/desirable behaviours (Moore and Rutherfurd, 2020). The reliability of recall is important for epidemiological studies: imperfect, but unbiased, recall could weaken potential associations with health outcomes; biased recall, for example, differing by diseased/not diseased or exposed/not exposed individuals, could either exaggerate or dilute estimated risks (Pearce *et al.*, 2007).

A systematic review on occupational pesticide exposures identified that approximately five times as many studies use indirect (e.g. self-reported) compared to direct (e.g. biomarkers) methods (Ohlander *et al.*, 2020). Despite the prevalence of this practice, few studies have assessed the reliability of self-reported information in agricultural workers. Studies in the USA and South Korea that examined the use of pesticides with recall periods of 4 weeks (Lee *et al.*, 2010), 1 year (Blair *et al.*, 2002), and 20 years (Engel *et al.*, 2001) found more accurate responses for broad practices, such as ever having used pesticides, compared to more detailed information (e.g. specific product used, frequency of application). In these studies, reliability of the use of specific pesticides was highest with the shortest recall period. In general, it is thought that more bias is expected with longer recall periods (Bound *et al.*, 2001); however, more information is needed regarding the extent to which recall of different exposure determinants may be biased (i.e. over or under reported) and how this may vary by length of follow-up time.

The Improving Exposure Assessment Methodologies for Epidemiological Studies on Pesticides (IMPRESS) project (www.impress-project.org) aims to improve understanding of the performance of pesticide exposure assessment methods used in previous epidemiological investigations, and to use this information to recommend enhancements in scientific practice for future studies (Jones *et al.*, 2020). One of the objectives of the IMPRESS project is to evaluate workers' recall of exposure to pesticides and other information on exposure determinants to estimate the direction and size of any recall bias and its effect on misclassification. In this paper, we describe the recall of pesticide exposure determinants over a range of time frames in three UK cohorts (the current Prospective Investigation of Pesticide Applicators' Health [PIPAH; Harding *et al.*, 2017] cohort, and two historical cohorts—the Pesticide Users' Health Study [PUHS; Frost *et al.*, 2011; Holmes, 2011] and the Study of Health in Agricultural Work [SHAW; Povey *et al.*, 2014]). Mueller *et al.* (under review) describe a similar assessment on the recall of farmers' pesticide use in a low-income country in the Pesticide Use in Tropical Settings (PESTROP) cohort (Staudacher *et al.*, 2020) that was also undertaken within the remit of the IMPRESS project.

Methods

Study setting

In the UK, cereals are the most common arable crop, with wheat and barley representing 42 and 27%, respectively, of all arable cropland in 2018. Other important arable crops include oilseed rape (14%) and spring barley (18%) (Garthwaite *et al.*, 2019). Pea and bean crops accounted for 34%, and brassicas 21%, of the total area of outdoor vegetables grown (Mace *et al.*, 2019), with four crops accounting for 84% of the total area of soft fruit grown: strawberries (34%); blackcurrants for processing (20%); grapevines (18%); and raspberries (12%) (Ridley *et al.*, 2020). By weight, herbicides and desiccants account for nearly half (49%) of all pesticides applied to arable cropland in the UK, with fungicides at 33%, growth regulators at 15%, and other products at 1% or less (Garthwaite *et al.*, 2019). In a recent survey of outdoor vegetable crops grown in the UK, there was a 7% increase in the pesticide-treated area in the UK between 2011 and 2019, with pesticides by weight applied increasing by 17% over this period (Mace *et al.*, 2019). Pesticides are also applied to grassland and fodder crops, as well as in the amenity sector, of which herbicide use represents over 95% of all active substances by weight (Barker *et al.*, 2018; Garthwaite *et al.*, 2018).

Participating cohorts

Pesticide Users' Health Study

The PUHS was established by the Health and Safety Executive (HSE) in the late 1990s. The aims of the study were to monitor the long-term health of individuals potentially exposed to low levels of pesticides on a long-term basis. From 1994 to 2003, anyone applying for certification (required by users of agricultural pesticides under the Control of Pesticides Regulations, 1986) was invited to give their permission for HSE to access their information for the purpose of medical research into pesticide use. Those who agreed became members of the PUHS (around 65 000 participants). In 2004 and 2006, HSE sent a questionnaire to all participants. As this is a historical cohort, only those participants who have been subsequently recruited into the PIPAH study (described below), and are currently active pesticide users, were contacted (*n* = 767 participants).

Prospective Investigation of Pesticide Applicators' Health Study

The UK PIPAH Study was established in 2013 to investigate evidence of a link between working with pesticides and health. All members of the National Register of Sprayer Operators and the National Amenity Sprayer Operators' Register were invited to take part in the study. Members of HSE's other long-term health study on pesticides, the PUHS (described above), who had completed the initial PUHS survey, were invited to join in 2014. Over 5700 baseline questionnaires have been completed to date, and enrolment is ongoing. A questionnaire covering pesticide use during the calendar year 2016 was sent to the whole cohort in January 2017, with 1340 responses received. For this recall study, all subjects who filled out the 2016 exposure questionnaire, and who were not PUHS-originating members, were invited to participate (*n* = 730).

Study of Health in Agricultural Work

SHAW was established in 2002 with a study population consisting of people who were identified as being farmers in the 1970s through contemporaneous records of the following four main sources: the National Farmers' Union, UK sheep associations, UK cattle associations, and Shepherd's Guides. Overall, the study was designed to assess whether low-dose pesticide exposure was associated with neuropsychiatric disorders in UK farmers. In phase 1, participants were sent a screening questionnaire that asked about their health and work history. Questionnaires were returned from 1380 subjects. Analyses provided evidence that handling the pesticide concentrate for the treatment of sheep was associated with screen-positive neuropathy and Parkinsonism (Povey *et al.*, 2014). Phase 2 of the study was designed as a case–cohort study of the original cohort, and a subgroup of the phase 1 cohort (*n* = 234) was interviewed in 2006–2008 to obtain more detailed information on ill health and exposure history. This smaller group formed the basis of the recruitment for the recall study.

Recruitment of participants

Cohort participants aged 18 years and over at baseline, and who completed a pesticide use questionnaire in the original study, were eligible for inclusion. Survey packs were sent to all eligible participants (N = 1731). Each survey pack was customized to the particular cohort and contained a letter of invitation, a participant information sheet, a consent form, a postage paid return envelope, and a questionnaire (PUHS and PIPAH cohorts). For better consistency with the initial administration method (in-person interview), and to adhere to COVID-19-related restrictions in effect at the time of recruitment, SHAW participants were interviewed by telephone. Although the questionnaire was not included in the survey pack, consented SHAW participants were sent prior to the telephone interview a brief timeline of their work histories and prompt cards listing different pesticides to use if desired during the interview, mirroring the original methodology [see Supplementary Material (available at *Annals of Occupational Hygiene* online) for all study questionnaires, SHAW timeline, and SHAW prompt cards]. The brief work history timeline included a simplified work history calendar from 1946 to 2006, indicating the years the farmer worked with livestock, crops, or undertook other work. For those who did not respond to the first mailing, a reminder survey pack was issued after 2–4 weeks for the SHAW cohort and within 3 months for the PIPAH/PUHS cohorts.

Questionnaires

Consented participants were questioned concerning exposure information from the first survey. Follow-up surveys took place in 2019 for PUHS/PIPAH and 2020–2021 for SHAW; therefore, timeframes for recall were 3 years for PIPAH, 13 years for PUHS, and 12–14 years for SHAW. Participants were administered a modified version of the original questionnaire to reflect the time periods of interest in the IMPRESS project (i.e. practices at the time of the original survey for PUHS/PIPAH; practices up to the time of the original survey for SHAW). The format and relevant questions were retained, but some extraneous questions from the original questionnaires (e.g. relating to health) were excluded for ethical (unused information) and practical (time needed to complete) reasons. In addition, all farmers in SHAW, in line with the original study protocol, were administered the retrieval of remote (e.g. famous events) and recent (e.g. current prime minister) information elements of the memory section of the Cambridge Cognition Examination instrument to allow for an assessment of their memory function (scored out of 10) (Roth *et al*., 2006). Table 1 provides summary information across the three cohorts, including response rates for the IMPRESS study.

Data analysis

We assessed recall bias in the three studies by comparing responses at follow-up regarding practices and behaviours to those initially reported in the baseline surveys. Although SHAW participants provided data related to their working histories, we matched recall only to the most recent data provided in the baseline interview. Only those PIPAH and PUHS subjects who used pesticides in their job at the time of baseline were included in the analysis, since those who did not use pesticides were not required to complete the full questionnaire. We excluded from analysis individuals from the PUHS cohort who responded to the 2004 questionnaire (n = 68), since the recall questionnaire asked about jobs in 2006. Specifically, we examined participant responses on the extent to which they could accurately recall the following exposure determinants: (i) time (years, days/hours per year) spent mixing and handling pesticides; (ii) crops or areas of work involving pesticide use; (iii) personal protective equipment (PPE) items worn while mixing or handling pesticides; (iv) hygiene habits, such as bathing and changing after handling pesticides; and (v) application method (see Supplementary Table S1, available at *Annals of Occupational Hygiene* online).

We used Spearman rank correlations to examine the agreement between baseline and recalled years, and annual days and hours, using pesticides with crops. Since this information was collected separately for each crop in the PIPAH and SHAW surveys, we summed the individual values to calculate the total reported annual days and hours; for SHAW, pesticide use was assumed to be '0' if none was reported with any crop. Maximum values of application were assumed to be 260 days per year (i.e. 52 weeks × 5 days) and 2080 hours per year (i.e. 260 days × 8 hours). We pooled the individual datasets for the three cohorts and calculated for each individual the geometric mean ratios (GMR) of recalled compared

Table 1. Questionnaire distribution years and response rates.

Study	Data year of original questionnaire	Time to recall (years)	Responded/invited to follow-up survey (n)	Response rate (%)
PUHS	2004, 2006	13	268/767	34.9
PIPAH	2016	3	336/730	46.0
SHAW	2006–2008	12–14	39/234	16.7

to initially reported years/days/hours working with pesticides: GMRs of >1.0 suggest overestimates at follow-up compared to baseline, whereas GMRs of <1.0 indicate underestimates. We used multiple linear regression with the GMRs as the dependent variable to examine any differences in recall by categories of demographic and other characteristics at the time of follow-up, namely sex, age (</≥ 60 years), experience (</≥ 40 years), and education (beyond secondary school/secondary or less), as well as between studies (Goedhart *et al.*, 2018). Covariates for this analysis were categorized based on approximate median values. Experience was ascertained categorically in PUHS and PIPAH questionnaires based on the number of years living/working on a farm; for SHAW, experience was calculated from the earliest reported start year working with crops or sheep. Analysis was completed for those individuals with non-missing data for all covariates and non-zero estimates of years/days/hours.

We calculated the sensitivity (i.e. the number of correct affirmative responses; true positives/[true positives + false negatives]), specificity (i.e. the number of correct negative responses; true negatives/[true negatives + false positives]), overall agreement, and area under the curve (AUC) values using the baseline responses as the gold standard for the five most reported crops, PPE items worn during mixing and handling pesticides (sheep dipping for SHAW participants per available data), and hygiene habits relevant for exposure. We also used these same indicators for application method, in which we examined the recall of any tractor (i.e. boom sprayer) or manual-based (i.e. hand-held sprayer, knapsack, mist/fogger, or manually handled) application. In addition, we calculated the reported prevalence at baseline to help interpret trends in the resulting agreement. Possible values of AUC range from 0 to 1.0, with values <0.7 considered to be non-useful; values of >0.7, >0.8, and >0.9 are fair, good, and excellent, respectively (Carter *et al.*, 2016). We calculated correlations between the total number of crops each participant originally reported and the agreement (i.e. yes or no) between recalled and baseline reported working with the five most common crops. We present these results separately for each study.

In addition, with the older ages of the SHAW participants, the overall change in general memory was assessed using the Cambridge Cognition Exam test scores. We used *t*-tests and paired *t*-tests to compare the responder and non-responder baseline scores, as well as the responder baseline/follow-up scores. To assess any associations between general and occupation-related memory, we examined the correlation between both the follow-up score and change in score from baseline with the recalled crops, PPE items, and methods of application, as presented below. All data analysis was performed using Stata v16 (StataCorp, 2019).

Results

There were 643 individuals who completed both the baseline and follow-up surveys in the three cohorts. The mean age at baseline ranged from mid-40s (PUHS) to mid-60s (SHAW). Each cohort was almost entirely male and had used pesticides (>90% in both instances). Approximately half of the subjects in each cohort had training beyond a secondary education. Of those using pesticides at the time of the baseline survey, 54 (25.3%) and 44 (14.0%) participants worked as contractors in PUHS and PIPAH, respectively. Most of the characteristics of the responders appeared to be comparable to those of the non-responders for each study, except for higher education in the PUHS and SHAW responders (see Table 2).

Although there was a strong correlation (rho = 0.77) between the baseline and recalled years working with pesticides for PUHS, overestimation on average by 18% was apparent at follow-up [GMR = 1.18 (95% confidence interval: 1.07–1.30)] (see Table 3; Figure 1). There was moderate to strong agreement in the recalled days (rho ≥ 0.51 across all three studies) and hours (rho ≥ 0.70 in PIPAH and SHAW) working with pesticides per year; recalled hours in the PUHS study was weaker (rho = 0.30). Participants in the SHAW cohort more than doubled estimates of recalled hours [GMR = 2.60 (95% CI: 1.15–5.86)], but no biases were apparent for either recalled hours or days in the other cohorts (see Table 3). There did not appear to be any major differences in the ability to recall years by demographic characteristics (see Supplementary Table S2, available at *Annals of Occupational Hygiene* online).

The overall agreement in the recall of the five most reported crops or areas of work in each study was in excess of 70%, except for amenity weed control in PUHS (62.7%) and grass in SHAW (65.7%). Sensitivity was poor (<43%) and AUC values were consistently <0.7 for PUHS (see Table 4). The mean (SD) number of crops/areas of work was 2.4 (1.4), 3.6 (1.7), and 3.5 (1.9) in PUHS, PIPAH, and SHAW, respectively, with weak negative and positive correlations between the number of crops and recall ability (i.e. correctly identifying if a given crop was grown), ranging from −0.36 to −0.12 in PUHS, −0.20 to 0.17 in PIPAH, and −0.06 to 0.21 in SHAW.

The use of PPE items was more common in PUHS/PIPAH than in SHAW. Overall agreement for PPE items ranged from 58 to 90%, with AUC values in each study

Table 2. Descriptive statistics of each cohort at the time of the first survey.

Characteristic	PUHS[1]		PIPAH		SHAW	
	n (%) or mean (SD)		*n* (%) or mean (SD)		*n* (%) or mean (SD)	
	Responders	Non-responders	Responders	Non-responders	Responders	Non-responders
	(*n* = 200)	(*n* = 491)	(*n* = 336)	(*n* = 394)	(*n* = 39)	(*n* = 195)
Age (years)	45.4 (9.1)	47.1 (10.1)	56.3 (9.4)	55.5 (11.7)	66.7 (5.5)	66.1 (5.5)
Missing	5	13	2	2	0	0
Sex						
Male	182 (93.3%)	447 (93.7%)	332 (99.4%)	382 (98.2%)	38 (97.4%)	186 (95.4%)
Female	13 (6.7%)	30 (6.3%)	2 (0.6%)	7 (1.8%)	1 (2.6%)	9 (4.6%)
Missing	5	14	2	5	0	0
Experience (years)[2]	23.5 (11.0)	24.4 (11.7)	36.6 (11.3)	36.1 (12.7)	43.2 (11.5)	39.8 (15.9)
Missing	0	25	0	3	0	8
Education						
Beyond secondary	121 (63.4%)	219 (46.3%)	162 (49.2%)	185 (48.2%)	20 (51.3%)	49 (25.1%)
Secondary or less	70 (36.6%)	254 (53.7%)	167 (50.8%)	199 (51.8%)	16 (41.0%)	145 (74.4%)
Missing	9	18	7	10	3 (7.7%)	1 (0.5%)
Use of pesticides[2,3]						
Ever	194 (99.5%)	473 (97.9%)	336 (100%)	393 (99.7%)	36 (92.3%)	185 (94.9%)
Never	1 (0.5%)	10 (2.1%)	0 (0%)	1 (0.3%)	0 (0.0%)	9 (4.6%)
Missing	5	8	0	0	3 (7.7%)	1 (0.5%)
Cambridge Cognition Scores	NA	NA	NA	NA	9.1 (1.1)	8.8 (1.2)
Missing	NA	NA	NA	NA	0	24

NA, not applicable; the Cambridge Cognition Examination was administered only in the SHAW study.
[1]Statistics estimated from the PIPAH Study 2014 baseline questionnaire to compare responders and non-responders.
[2]With crops or sheep for SHAW.
[3]With crops for PUHS and PIPAH (past year only for PIPAH).

both below and above 0.7 (see Table 5; Supplementary Table S3, available at *Annals of Occupational Hygiene* online). There was variation in the frequency of hygiene habits, which were only available from PIPAH, ranging from approximately one third of subjects bathing right after pesticide use to nearly all (>99%) washing their hands before eating. Overall agreement was 75% or higher for the five habits assessed, with AUC values > 0.7 except in the case of removing boots outside the home (AUC = 0.65) (see Supplementary Table S4, available at *Annals of Occupational Hygiene* online).

Application of pesticides using a boom sprayer mounted on a tractor was more commonly used than manual application methods in the PIPAH and SHAW studies (i.e. >70% versus <10%). Recall of tractor method applications tended to be overestimated in PIPAH (i.e. specificity = 34.1%), as were manual methods in SHAW (i.e. specificity = 55.0%) (see Supplementary Table S5, available at *Annals of Occupational Hygiene* online).

There was no clear statistical difference in the baseline Cambridge Cognition scores between the SHAW responders (mean = 9.1; SD = 0.18) and non-responders (mean = 8.8; SD = 0.09) (*P*-value = 0.124), with a borderline decline from the baseline to follow-up (mean = 8.8; SD = 0.17) scores (*P*-value = 0.062). Correlations were weak between correct recall and both follow-up scores and changes in scores, which ranged from $r = -0.22$ to 0.14 and $r = -0.28$ to 0.23 (*P*-value > 0.05 in all cases), respectively.

Discussion

We examined the accuracy of recalled pesticide use in farmers and pesticide applicators, and other information on exposure determinants, using three UK-based cohorts with recall periods ranging from 3 to 14 years. We found recalled years working with pesticides to be overestimated, but did not find this varied by demographic characteristics, including age at recall. While overall agreement was >70% for many of the exposure determinants, recall ability varied depending on the specific study and associated recall period.

Table 3. Overall agreement (95% confidence intervals) in the three cohorts of baseline and recalled years, days, and hours mixing and applying pesticides (statistically significant [$P < 0.05$] Geometric Mean Ratios are in bold).

Unit of recall	PUHS	PIPAH	SHAW
Years			
n (participants)	132	NA	NA
Mean at baseline (SD)	15.5 (11.3)	NA	NA
Mean at recall (SD)	17.3 (11.3)	NA	NA
Correlation (rho)	0.77	NA	NA
Geometric mean ratio	**1.18 (1.07–1.30)**	NA	NA
Days per year			
n (participants)	114	305	14
Mean at baseline (SD)	26.9 (38.2)	44.5 (47.1)	27.6 (67.4)
Mean at recall (SD)	23.4 (25.1)	39.9 (37.5)	37.9 (61.4)
Correlation (rho)	0.51	0.66	0.79
Geometric mean ratio	1.03 (0.986–1.24)	0.95 (0.87–1.04)	1.74 (0.88–3.46)
Hours per year			
n (participants)	99	295	14
Mean at baseline (SD)	62.0 (94.1)	284.1 (363.5)	180.5 (413.2)
Mean at recall (SD)	54.7 (80.2)	262.4 (330.2)	258.6 (323.5)
Correlation (rho)	0.3	0.7	0.76
Geometric mean ratio	0.88 (0.63–1.21)	0.97 (0.87–1.08)	**2.60 (1.15–5.86)**

NA, not applicable; years of pesticide use was not asked in PIPAH and SHAW questionnaires.

Frequency of application

Only one of the three cohorts (PUHS; 13-year recall period) included estimates of years using pesticides, which, although baseline and recalled values were strongly correlated, appeared to be overestimated by 18% on average at follow-up (equivalent to nearly 3 years). Recall may also depend on the context in which the initial survey took place. For example, Engel *et al.* (2001) hypothesized that the observed over-reporting of herbicides and fungicides was possibly due to the expansion of those products around the time of the baseline survey.

Other studies with much shorter recall periods have also found at least moderate correlations for reported number of years, showing better agreement than for reported number of days (Lee *et al.*, 2010; Mueller *et al.*, under review) or hours (Blair *et al.*, 2002; Lee *et al.*, 2010; Mueller *et al.*, under review). In our study, we also found moderate to strong correlations in recalled days mixing and applying pesticides per year, with no suggestion of bias in under- or over-reporting. Recalled hours per year were less reliable, with only a weak correlation in the PUHS study and evidence of overestimation in the SHAW cohort (rho = 0.76); both studies entailed longer recall periods of 12–14 years. It may be difficult to accurately recall hours using pesticides over the course of a year, which is more likely to be an estimate (Stull *et al.*, 2009). Even across very short term periods, research with turf applicators that compared recalled to recorded hours sprayed in the prior week showed only moderate correlation, with some overestimation (Harris *et al.*, 2005). It is notable that participants in both studies with longer recall periods involved overestimation of years (PUHS) and hours (SHAW), which may have been conflated with experience gained subsequent to the baseline survey. Ultimately, regardless of the underlying mechanism, these findings, as well as those reported elsewhere, provide some support of greater bias with longer recall periods (Bound *et al.*, 2001).

We observed no differences in reporting by demographic characteristics (i.e. age, education, experience), with the exception of more inflated estimates of hours among females (albeit based on a small sample size). Most studies have not examined the potential influence of these attributes in the reporting of frequency of pesticide use, though our results agree with Mueller *et al.* (under review), who also did not find any such differences in recall among Ugandan smallholder farmers.

Crops

While the overall agreement was mainly over 70% for the recalled crops on which pesticides were applied, there were differences among the three cohorts, with better recall in PIPAH (75.5–97.2%) than in PUHS

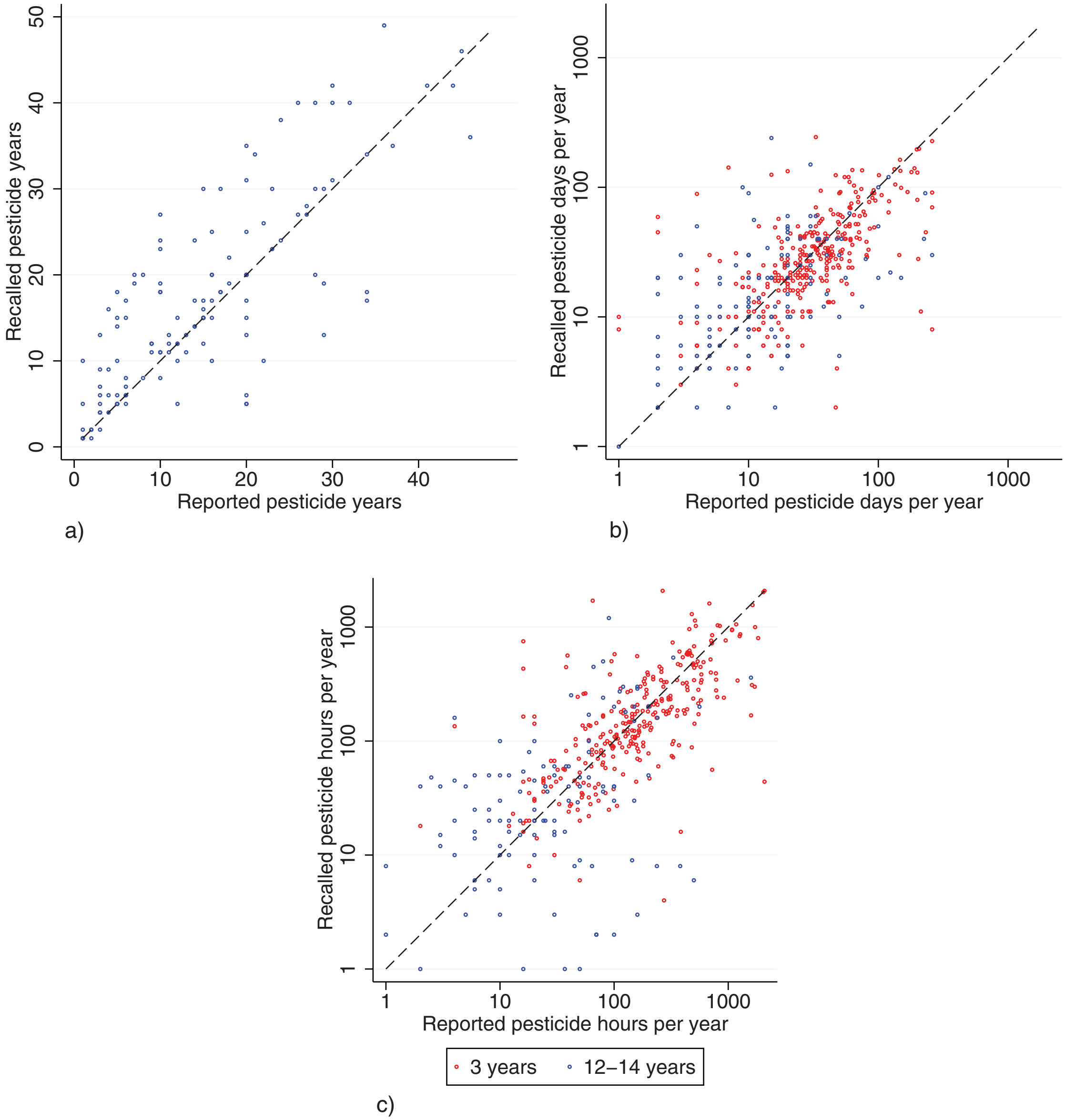

Figure 1. Scatterplots of recalled versus reported (a) years (PUHS only), (b) days per year (log-scale), and (c) hours per year (log-scale) working with pesticides for all three cohorts. The dashed reference line represents perfect agreement.

(62.7–84.4%); participants in the latter study tended to under-report. Better recall in PIPAH may be due to a shorter interval between the survey periods (i.e. 3 years versus 13 years). Interestingly, although the SHAW study had a similar recall period to PUHS, participants tended to over report crops and had slightly better overall agreement and AUC values. The SHAW findings are based on a limited response rate, which also might be biased towards better reporters; in addition, the SHAW follow-up used a telephone interview (versus self-reported questionnaire in PUHS), which may have affected their recall.

One might expect that recall ability may be hindered by a larger number of crops on which pesticides were applied, but we found weak negative correlations only in the PUHS study, meaning the overall number of crops had little impact on recall for a given crop. The agreement of specific crops in the present study is better than that observed in a tropical context, where there are often numerous crops and multiple harvesting periods,

Table 4. Recall of the five most reported crops or area of work involving pesticide use by cohort.

Crop	*N*	Baseline prevalence	Recalled prevalence	Prevalence ratio	Sensitivity (%)	Specificity (%)	Overall agreement (%)	AUC
		n (%)	*n* (%)					
(a) PUHS								
Amenity weed control	150	79 (52.7)	37 (24.7)	0.47	38	90.1	62.7	0.64
Golf courses	148	33 (22.3)	10 (6.8)	0.3	18.2	96.5	79.1	0.57
Grassland	149	36 (24.2)	20 (13.4)	0.56	36.1	93.8	79.9	0.65
Cereals	148	35 (23.7)	25 (16.9)	0.71	42.9	91.2	79.7	0.67
Forestry	147	24 (16.3)	7 (4.8)	0.29	16.7	97.6	84.4	0.57
(b) PIPAH								
Cereals	323	277 (85.8)	284 (87.9)	1.03	99.6	82.6	97.2	0.91
Oilseeds	323	172 (53.3)	177 (54.8)	1.03	94.2	90.1	92.3	0.92
Farm yards or gardens	323	150 (46.4)	177 (54.8)	1.18	82.7	69.4	75.5	0.76
Grassland/fodder crops	323	116 (35.9)	133 (41.2)	1.15	78.5	79.7	79.3	0.79
Other arable crops	323	109 (33.8)	85 (26.3)	0.78	56.9	89.3	78.3	0.73
(c) SHAW								
Barley	35	16 (45.7)	22 (62.9)	1.38	87.5	57.9	71.4	0.73
Outdoor vegetables/potatoes	35	11 (31.4)	13 (37.1)	1.18	63.6	75	71.4	0.69
Wheat	35	10 (28.6)	17 (48.6)	1.7	90	68	74.3	0.79
Grass	35	10 (28.6)	16 (45.7)	1.6	70	64	65.7	0.67
Rapeseed	35	6 (17.1)	7 (20.0)	1.17	100	96.6	97.1	0.98

Table 5. Recall of the five most reported PPE items when mixing or handling pesticides in (a) and (b) or sheep dipping in (c).

PPE item	N	Baseline prevalence	Recalled prevalence	Prevalence ratio	Sensitivity (%)	Specificity (%)	Overall agreement (%)	AUC
		n (%)	n (%)					
(a) PUHS								
Gloves	150	144 (96.0)	137 (91.3)	0.91	92.4	33.3	90	0.63
Coveralls	147	127 (86.4)	101 (68.7)	0.8	75.6	75	75.5	0.75
Boots	148	114 (77.0)	104 (70.2)	0.91	81.6	67.7	78.4	0.75
Face shield	146	110 (75.3)	80 (54.8)	0.73	65.5	77.8	68.5	0.72
Respirator	144	29 (20.1)	27 (18.8)	0.93	51.7	89.6	81.9	0.71
(b) PIPAH*								
Gloves	323	290 (89.8)	304 (94.1)	1.05	95.9	21.2	88.2	0.59
Boots	323	281 (87.0)	267 (82.7)	0.95	87.9	52.4	83.3	0.7
General work wear	323	233 (72.1)	156 (48.3)	0.67	54.5	67.8	58.2	0.61
Face shield	323	223 (69.0)	206 (63.8)	0.92	80.3	73	78	0.77
CE-marked clothes	323	142 (44.0)	175 (54.2)	1.23	75.4	62.4	68.1	0.69
(c) SHAW#								
Boots	28	25 (89.3)	19 (67.9)	0.76	72	66.7	71.4	0.69
Leggings	28	14 (50.0)	15 (53.6)	1.07	64.3	57.1	60.7	0.61
Apron	28	12 (42.9)	11 (39.3)	0.92	66.7	81.3	75	0.74
Gloves	28	11 (39.3)	16 (57.1)	1.45	100	70.6	82.1	0.85

*Liquid pesticides.
#Other PPE items are based on n<5.

contributing to greater challenges in accurate recollection (Mueller *et al.*, under review).

PPE items

In the two cohorts in which PPE was reported for pesticide use on crops (i.e. PUHS, PIPAH), gloves, coveralls/work wear, boots, and a face shield were reported by at least 60% of farmers. This contrasts with the SHAW cohort, in which PPE was reported specifically for use during sheep dipping and where reported prevalences were 50% or lower, with the exception of boots, which was 89%. Despite these differences, overall agreement for items in the three studies ranged from approximately 60–90%, with no consistent trends in sensitivity or specificity. These patterns of PPE use are comparable to or greater than those reported in other high-income nations (e.g. Garrigou *et al.*, 2020), and much higher than those used in low and middle income (LMIC) settings (e.g. Chitra *et al.*, 2006; Lekei *et al.*, 2014; Mueller *et al.*, under review). However, responders in two of the cohorts (PUHS, SHAW) represented a higher proportion of more educated individuals, who may be more likely to wear PPE (Sapbamrer and Thammachai, 2020); thus, their PPE use might have differed from the group of non-responders.

Hygiene habits

Reported hygiene habits were similar to those reported in some studies regarding hand washing and bathing after mixing and application (Mekonnen and Agonafir, 2002; Negatu *et al.*, 2016), but lower for changing clothes and bathing (Riccò *et al.*, 2018). While there was variation across the hygiene practices, overall agreement was consistently over 75% and was over 90% both for washing hands before eating and removing boots outside the home.

Application method

The most prevalent application method by far (i.e. prevalence of ≥72%) involved a boom sprayer with a tractor, which was overestimated at follow-up in the PIPAH study. Manual application was overestimated in the SHAW cohort. Tractor application methods in the UK, where there are larger land areas, are typical (Wong *et al.*, 2018); therefore, applicators who could not remember with certainty may have tended to assume tractor methods were used. Anchoring questions, such as date of tractor purchase, have been shown to improve recall accuracy (Hoppin *et al.*, 1998), though these may be less relevant with a shorter recall period (such as in 3 years in PIPAH). Unfortunately, we are not aware of other studies that assess recall between manual and tractor application methods.

Cognitive test

Scores of the retrieval of remote and recent information elements of the memory section of the Cambridge Cognition Examination instrument were borderline lower than baseline 12–14 years later. Some decline in cognitive abilities would be expected, given the age of participants at the follow-up survey. We did not observe any association between memory scores and recall ability, but this was hindered by the restricted sample size in SHAW, as well as only modest changes in memory scores over time. The baseline scores of responders and non-responders were similar to older populations without dementia, as reported elsewhere (Huppert *et al.*, 1996). While there was no observable difference at baseline between responders and non-responders, there may have been more reduction in abilities in the non-responders by the time of the follow-up survey, as cognitive decline has been identified as a predictor for longitudinal attrition (Matthews *et al.*, 2004); nevertheless, it was not possible to test this.

Strengths and limitations

Our study represents the first in the UK to assess recall accuracy of farmers' and applicators' self-reported pesticide use and other important exposure information. We examined recall over different lengths of time, and our research findings extend the evidence base of recall bias involving occupational pesticide use by examining novel characteristics of exposure recall, such as the use of PPE and method of application. These perspectives on different aspects of recall could help with the interpretation of past studies that used different exposure metrics and could also help inform more accurate exposure assessment in future investigations of occupational pesticide exposure. Nevertheless, there are some limitations to discuss in our effort. We did not collect information at follow-up on specific active ingredients in PUHS and PIPAH and therefore could not investigate this recall ability. Response rates in each of the studies was less than 50%, and only 16.7% in the SHAW study; although most characteristics of responders and non-responders appeared similar, responders might not be representative of the total group. Response rates are expected to be lower for longer follow-up periods, especially in older cohorts, where deaths can lead to higher attrition rates; furthermore, healthier individuals may have been more likely to respond (Goldberg *et al.*, 2006). SHAW participants were interviewed by telephone, as it was not possible to re-interview face to face per baseline, primarily due to the COVID-19 pandemic. It is possible that less information was provided in telephone than face-to-face interviews (De Leeuw and van der Zouwen, 1988). SHAW participants were provided with timelines to track their working histories, which may have improved recall ability, but for analysis, we only compared the most recent year of work reported. As well, we considered the baseline responses to be the 'gold standard' with which to compare recall, but this information, too, was subjective and may not have accurately depicted true exposure levels. The validation of self-reported information will be addressed in another component of the IMPRESS project, which will examine biomarkers of short-term exposure to active ingredients as an objective estimate of exposure.

Conclusion

We examined farmers' and pesticide applicators' recall of pesticide exposure determinants in three UK studies with short (3 years) and long (12–14 years) recall periods. Certain recalled elements from ≥12 years' prior were found to be biased in either direction, involving over-reporting (e.g. years) and under-reporting (e.g. crops), which would lead to inflated and underestimated exposures, respectively. We did not find differences in recall ability by demographic characteristics, such as age, or contextual information, such as the number of crops on which pesticides were applied. Results did appear to indicate that recall ability may deteriorate over a longer interval period. Although lower response rates may require these findings to be interpreted with caution, recall for several exposure determinants appeared reliable, such as crops and hygiene practices within a few years, as well as days per year working with pesticides.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

Table S1. Recalled exposure information collected in each study.

Table S2. Regression model coefficients (95% confidence intervals) of the geometric mean ratio of recalled to baseline years (n = 132), days (n = 433), and hours (n = 408) per year mixing and applying pesticides. Coefficients represent estimation relative to the reference group. Adjusted for all parameters in the table at the time of follow-up, plus cohort.

Table S3. Recall of the five most reported PPE items when mixing or handling dry pesticides in the PIPAH cohort.

Table S4. Washing and changing behaviours after pesticide use (PIPAH only).

Table S5. Baseline and recalled application method for pesticide use on crops.

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Ethical approvals

PUHS and PIPAH cohorts: Ethical approval for the study was obtained from the University of Sheffield's Research Ethics Committee (REC) for the assessment of recall bias. The Greater Manchester Central REC gave approval for the PUHS to share individual-level data collected as part of the 2004–2006 Survey of Pesticide Usage with the PIPAH study.

SHAW: Ethical approval was obtained from the West Midlands Multi-Centre Research Ethics Committee (MREC/02/7/115) and the University of Manchester Ethics Committee (study 3156).

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Conflict of interest

No conflicts of interest are declared. The contents, including any opinions and/or conclusions expressed of this manuscript, are those of the authors alone and do not necessarily reflect the opinions or policy of the organizations to which they are employed.

Data Availability

The data underlying this article cannot be shared publicly due to the privacy of individuals that participated in the study.

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