Neurobehavioral Performance and Work Experience in Florida Farmworkers

Freya Kamel,[1] Andrew S. Rowland,[2] Lawrence P. Park,[3] W. Kent Anger,[4] Donna D. Baird,[1] Beth C. Gladen,[1] Tirso Moreno,[5] Lillian Stallone,[6] and Dale P. Sandler[1]

[1]National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina, USA; [2]University of New Mexico, Albuquerque, New Mexico, USA; [3]Westat, Durham, North Carolina, USA; [4]Oregon Health and Science University, Portland, Oregon, USA; [5]Farmworkers Association of Florida, Apopka, Florida, USA; [6]CODA, Durham, North Carolina, USA

Farmworkers experience many work-related hazards, including exposure to neurotoxicants. We compared neurobehavioral performance of 288 farmworkers in central Florida who had done farm work for at least 1 month with 51 controls who had not. Most of the farmworkers had worked in one or more of three types of agriculture: ornamental ferns, nurseries, or citrus fruit. We collected information on farm work history in a structured interview and evaluated neurobehavioral performance using a battery of eight tests. Analyses were adjusted for established confounders including age, sex, education, and acculturation. Ever having done farm work was associated with poor performance on four tests—digit span [odds ratio (OR) = 1.90; 95% confidence interval (CI), 1.02–3.53], tapping (coefficient = 4.13; 95% CI, 0.00–8.27), Santa Ana test (coefficient = 1.34; 95% CI, 0.29–2.39), and postural sway (coefficient = 4.74; 95% CI, –2.20 to 11.7)—but had little effect on four others: symbol digit latency, vibrotactile threshold, visual contrast sensitivity, and grip strength. Associations with farm work were similar in magnitude to associations with personal characteristics such as age and sex. Longer duration of farm work was associated with worse performance. Associations with fern work were more consistent than associations with nursery or citrus work. Deficits related to the duration of work experience were seen in former as well as current farmworkers, and decreased performance was related to chronic exposure even in the absence of a history of pesticide poisoning. We conclude that long-term experience of farm work is associated with measurable deficits in cognitive and psychomotor function. ***Key words:*** **citrus fruit, cognitive function, farm work, neurobehavioral performance, nurseries, ornamental ferns, psychomotor function.** ***Environ Health Perspect*** **111:1765–1772 (2003). doi:10.1289/ehp.6341 available via *http://dx.doi.org/* [Online 23 July 2003]**

Farmworkers are exposed to numerous hazards in the course of their work, including injury and exposure to pesticides and other toxicants (Moses et al. 1993; Villarejo and Baron 1999). Farmworkers are a vulnerable occupational group: They are often foreign-born and may not speak English; they may lack formal education; and they and their families often live in poverty. The agricultural industry is exempt from many federal regulations governing the workplace, and farmworkers are rarely represented by labor unions. Potential adverse health effects of farm work include traumatic injury, musculoskeletal disorders, respiratory conditions, dermatitis, cancer, and neurologic disorders. Some of these conditions may be related to pesticide exposure (Das et al. 2001; Keifer and Mahurin 1997; Moses et al. 1993). The health effects of farm work are compounded by the relative lack of access of this group to medical information and care.

Farmworkers in several settings have been reported to experience elevated rates of neurologic dysfunction. For example, they had increased frequency of neurologic symptoms (Ciesielski et al. 1994; Gomes et al. 1999) and decreased performance on some neurobehavioral tests (Bazylewicz-Walczak et al. 1999; Gomes et al. 1999; Rohlman et al. 2001) compared with unexposed workers. Farmworkers with a history of pesticide poisoning experienced more symptoms and had impaired neurobehavioral performance relative to nonpoisoned controls (McConnell et al. 1994; Rosenstock et al. 1991; Wesseling et al. 2002).

We report here the results of a large, population-based study of farmworkers in central Florida. The focus of the study was the relationship of long-term experience of farm work to neurobehavioral performance and potential differences related to type of farm work. We took into account important confounders, including education and acculturation.

Materials and Methods

Population. We conducted a cross-sectional study in central Florida in 1996–1997. Study participants were recruited in collaboration with the Farmworkers Association of Florida, a farmworker advocacy group (Kamel et al. 2001). Our target population was members of the Community Trust Federal Credit Union and their spouses. The Credit Union is a small savings institution with branches in several Florida communities. It is affiliated with several community organizations, including the Farmworkers Association; many but not all of its members are farmworkers. Credit Union members were typical members of the local communities (Kamel et al. 2001).

We randomly selected names from the membership lists of the Credit Union in two communities, Apopka and Pierson. Most farmworkers in these communities had worked in one of three types of agriculture: growing and harvesting ornamental ferns, working in nurseries, or picking citrus fruit. Bilingual recruiters chosen by the Farmworkers Association located the selected individuals and administered a screening interview to determine eligibility and to identify spouses of credit union members, who were then also screened. To reduce variability in neurobehavioral performance, we restricted the age range to 28–55 years of age and excluded individuals with diabetes, epilepsy, or stroke. We recruited men and women of any race or ethnicity who were fluent in Spanish or English. We screened 80% of selected individuals, and 81% of those eligible participated in the study (Kamel et al. 2001).

We recruited 288 individuals who had ever done farm work for at least 1 month (farmworkers) and 51 controls who did not meet this criterion. Participants in the study completed a structured interview and a battery of neurobehavioral tests. They received $50 as compensation for their time and effort. Institutional review boards of the National Institute of Environmental Health Sciences and CODA approved the study, and all participants signed a written consent form.

Interview. We collected information on history of farm work, other employment, demographics, lifestyle, and medical history in a structured interview administered in person by trained personnel; a complete copy of the questionnaire is available (Farmworkers Health Study 2003). The interview took an average of 57 min (range, 15–155 min) and was conducted in Spanish (85%) or English (15%), depending on the respondent's preference. Farm work history included questions on total years of farm work and on farm work in the year before the interview, before age 14, or as a migrant worker. We collected detailed job histories for work with ferns, in nurseries,

Address correspondence to F. Kamel, Epidemiology Branch, National Institute of Environmental Health Sciences, Box 12233, MD A3-05, Research Triangle Park, NC 27709 USA. Telephone: (919) 541-1581. Fax: (919) 541 2511. E-mail: kamel@niehs.nih.gov

We are grateful to the staff of the Farmworkers Association of Florida, particularly G. Grimes, A. Bahena, C. Cabrera, L. Milien, and R. Rodriguez; to the CODA study supervisors G. Ramírez-Garnica and M. Bizzio; to D.S. Rohlman and O.J. Sizemore for developing the test battery; and to the community members who participated in the study.

The authors declare they have no conflict of interest.

Received 18 March 2003; accepted 23 July 2003.

or picking citrus fruit, asking about total years and months per year worked for each job and the number of bunches of ferns cut per day for fern jobs.

The interview also included questions on ethnicity, years of formal education, and degree of acculturation, defined as likelihood of speaking English with friends (not acculturated = never; somewhat acculturated = less than half the time; very acculturated = half the time or more); the latter question is adapted from the third National Health and Nutrition Examination Survey (2003). We collected information on cigarette smoking and consumption of alcoholic beverages, the latter including a measure of frequency during the past year and a lifetime history of problems with family life, work, or health related to alcohol use. We asked about usual lifetime occupation and type of work during the 2 months preceding the interview. Medical history included questions on head injury, neck or back injury, and pesticide poisoning. Participants were asked to describe the location of any pain, tingling, or numbness experienced during the preceding 2 months in their fingers, hands, wrists, or arms. We collected information on the 24-hr period preceding testing, including consumption of alcoholic beverages, use of prescription medications, and any illness. Participant characteristics are shown in Table 1.

Table 1. Characteristics of study participants.[a]

Characteristics	Controls (*n* = 51)	All farmworkers (*n* = 288)	Fern workers (*n* = 140)	Nursery workers (*n* = 147)	Citrus workers (*n* = 141)
Age (years)					
28–32	24	24	26	24	21
33–37	22	29	27	25	28
38–43	20	26	29	23	26
44–55	35	21	19	28	26
Mean ± SD	39.9 ± 7.3	38.0 ± 6.7	37.8 ± 6.4	38.8 ± 7.3	39.0 ± 7.1
Sex					
Male	41	56	56	54	65
Female	59	44	44	46	35
Ethnicity					
Latino	63	89	94	82	84
Non-Latino white	18	3	0	6	4
Other	20	8	6	12	13
Education (years)					
0–5	12	39	45	35	43
6–11	24	42	41	37	36
≥ 12	65	19	14	27	21
Mean ± SD	11.9 ± 4.8	6.5 ± 4.2	5.8 ± 4.1	7.2 ± 4.5	6.4 ± 4.5
Acculturation					
Not acculturated	22	54	66	41	43
Somewhat acculturated	31	26	21	28	31
Very acculturated	47	20	12	31	26
Language of testing					
Spanish	63	89	94	81	83
English	37	11	6	19	17
Lifetime cigarette smoking (pack-years)					
Never	57	54	60	44	46
> 0–5	22	29	24	37	33
> 5–15	10	11	12	12	13
> 15	12	6	4	7	8
Alcohol use in previous year (drinks per week)					
< 1	63	59	64	60	52
1–14	31	26	24	27	32
≥ 15	6	15	12	14	16
Lifetime problems with alcohol use					
Never drank	33	30	33	27	21
Drank, no problems	49	47	44	47	50
Drank, had problems	16	23	23	26	29
Usually sleep ≥ 7 hrs					
Yes	71	81	81	80	79
No	29	19	19	20	21
20:20 vision					
Left eye					
Yes	65	68	69	66	70
No	35	31	31	34	30
Right eye					
Yes	63	69	72	68	67
No	37	31	27	32	33
Ever had severe head injury					
No	88	93	90	94	93
Yes	12	7	10	6	7
Ever had any neck or back injury					
No	75	78	79	78	77
Yes	25	22	21	22	23
Hand pain					
Preferred hand					
No	82	83	80	85	82
Yes	18	17	20	15	18
Nonpreferred hand					
No	80	88	91	86	88
Yes	20	12	9	14	12

[a]Table entries are column percentages except where indicated. Many farmworkers had worked on more than one crop, so the sum of fern, nursery, and citrus workers is greater than the total number of farmworkers.

Neurobehavioral testing. Because previous studies provided only limited information regarding which aspects of neurologic function would be affected by pesticides, we evaluated neurobehavioral performance using a battery designed to address neurologic function broadly. The battery included eight tests: digit span, symbol digit latency, vibrotactile threshold, visual contrast sensitivity, tapping, Santa Ana (a type of pegboard test), grip strength, and postural sway. Digit span and symbol digit latency are tests of cognitive function; vibrotactile threshold and visual contrast sensitivity, of sensory function; tapping and Santa Ana, of psychomotor function; grip strength, of motor function; and postural sway, of balance, an integrated sensorimotor function. Digit span, symbol digit latency, and Santa Ana are recommended tests in the World Health Organization Neurobehavioral Core Test Battery (Anger et al. 2000). We also measured visual acuity, as a potential confounder. The testing took an average of 65 min (range, 30–122 min), and was conducted in the same language as the interview.

Digit span, symbol digit latency, and tapping were presented on a computer using the Behavioral Assessment and Research System (BARS; Anger 2003; Rohlman et al. 2000a, 2000b, 2003). Participants responded on an external unit consisting of nine large buttons that fit over the computer keyboard. Integral Spanish or English instructions and practice were used to teach participants to perform the BARS tests (Anger 2003; Rohlman et al. 2000a, 2000b, 2003). Examiners taught appropriate performance on the other tests orally. Vibrotactile threshold was assessed for the index and fourth digits of both hands using a Vibratron II (Physitemp Instruments, Clifton, NJ). Visual acuity and visual contrast sensitivity were assessed for right and left eyes using an Optec 1000 (Stereo Optical Co, Chicago, IL). Visual contrast sensitivity was measured at five spatial frequencies for each eye: 1.5, 3, 6, 12, and 18 cycles per degree (cpd). Participants wore their usual glasses during the vision tests. Santa Ana was administered using a pegboard constructed according to Neurobehavioral Core Test Battery specifications (Anger et al. 2000). Grip strength was measured with a dynamometer (Jandel, San Rafael, CA). Postural sway was assessed using an Accusway Balance Platform (Minimitter, Bend, OR) under four conditions: 1, eyes open, no foam; 2, eyes closed, no foam; 3, eyes open, standing on a foam rubber pad; 4, eyes closed, on foam. Postural sway data were acquired directly on a computer using software provided by the manufacturer.

Most of the tests had several different measures (Table 2). In many cases, these were correlated with each other (digit span, r = 0.45; vibrotactile threshold, r = 0.55–0.80; visual contrast sensitivity, r = 0.31–0.75; tapping, r = 0.45–0.77; Santa Ana, r = 0.66; postural sway, r = 0.23–0.56).

Data analysis. Data were analyzed using SAS software, version 8.2 (SAS Institute Inc., Cary, NC). Digit span results were analyzed using ordinal logistic regression because the limited range of the data made results from linear regression unstable. Odds ratios (ORs) and 95% confidence intervals (95% CIs) for worse performance (i.e., fewer digits) are presented. All other test measures were analyzed using linear regression; coefficients and 95% CIs are presented. Vibrotactile threshold results were log-transformed to reduce skewness; other measures were more normally distributed and therefore not transformed. After analysis, the signs of coefficients and 95% CIs were reversed for visual contrast sensitivity, tapping, Santa Ana, and grip strength so that in all cases a higher value represents worse performance. Tests for dose–response trends were conducted using models including years of farm work as an ordinal variable and assessing significance of this variable using the likelihood ratio test for logistic models or the partial F-test for linear models.

Variables were considered as potential confounders for particular neurobehavioral tests based on *a priori* hypotheses regarding potential relationships. Age, sex, education, acculturation, time of day of testing, cigarette smoking (pack-years), alcoholic drinks per week, history of problems associated with alcohol use, usual hours of sleep, head injury, and neck or back injury were evaluated for all tests. Height and weight were evaluated for vibrotactile threshold, grip strength, and postural sway. Visual acuity was evaluated for all tests except grip strength. Hand pain was evaluated for vibrotactile threshold and grip strength. Age was used as a continuous variable except in models for visual contrast sensitivity and postural sway, where the relationship was not linear, so it was used as a categorical variable. Because ethnicity, years of formal education, acculturation, and language of testing were highly associated with one another, only education and acculturation were considered. Hand pain was scored positive if symptoms were consistent with carpal tunnel syndrome (Katz et al. 1991). Base models containing potential confounders were constructed by backward elimination; variables were retained in the models if $p < 0.10$. Final base models for the tests are shown in Table 3, with values for the specific measure that was explored in most detail; the same base variables were used for each measure of a test.

We evaluated the measures of exposure shown in Table 4. "Farm work" was defined as all types of farm work, including but not restricted to fern, nursery, and citrus work. "Ever" was defined as ≥ 1 month performing the activity. Initial analyses focused on the effects of ever exposure to general farm work or the three different types of farm work; subsequent analyses focused on duration of work. Variables for fern, nursery, and citrus work were constructed to evaluate each type of farm work separately from the other types. For example, the ever fern work variable had three categories: no farm work (referent), other farm work but no fern work, and fern work. The variable for months of fern work had five categories: no farm work (referent), other farm work but no fern work, ≤ 100 months of fern work, 101–140 months of fern work, > 140 months of fern work (approximate tertiles). Variables for nursery and citrus work were constructed analogously.

Results

Characteristics of study participants. Compared with controls, farmworkers were slightly younger and more likely to be male (Table 1). Mean (± SD) height and weight were 64.1 ± 3.4 inches and 169.9 ±33.0 pounds, respectively, for all study participants, and did not vary by group. A higher proportion of farmworkers than controls were Latino/a, and farmworkers had fewer years of formal education and were less acculturated than controls; these tendencies were most pronounced for fern workers. Farmworkers, particularly fern workers, were more likely than controls to choose to take the tests in Spanish. There was little difference among groups in the time of day tests were taken (data not

Table 2. Neurobehavioral test measures in controls and farmworkers

Test measures	Controls		Farmworkers	
	No.[a]	Mean ± SD	No.[a]	Mean ± SD
Cognitive function				
Digit span forward	51	5.63 ± 1.02	285	4.74 ± 0.99
Digit span reverse	51	4.12 ± 1.07	285	3.52 ± 1.00
Symbol digit latency	49	2,232 ± 774	273	2,680 ± 932
Sensory function				
Vibrotactile threshold PR digit 1	50	0.51 ± 0.19	281	0.56 ± 0.33
Vibrotactile threshold PR digit 4	50	0.55 ± 0.23	281	0.54 ± 0.31
Vibrotactile threshold NP digit 1	50	0.53 ± 0.26	279	0.48 ± 0.29
Vibrotactile threshold NP digit 4	50	0.53 ± 0.28	280	0.51 ± 0.29
Contrast sensitivity L eye 1.5 cpd	51	23.1 ± 13.0	287	21.5 ± 14.3
Contrast sensitivity L eye 3 cpd	51	35.0 ± 36.4	287	34.0 ± 24.7
Contrast sensitivity L eye 6 cpd	51	64.3 ± 56.8	287	66.4 ± 58.6
Contrast sensitivity L eye 12 cpd	51	42.5 ± 37.5	287	45.8 ± 34.9
Contrast sensitivity L eye 18 cpd	51	16.1 ± 13.4	287	16.1 ± 12.4
Contrast sensitivity R eye 1.5 cpd	51	21.1 ± 9.7	287	23.0 ± 17.7
Contrast sensitivity R eye 3 cpd	51	37.7 ± 33.0	287	36.3 ± 24.9
Contrast sensitivity R eye 6 cpd	51	63.8 ± 53.3	287	68.2 ± 51.2
Contrast sensitivity R eye 12 cpd	51	39.9 ± 34.7	287	50.5 ± 36.0
Contrast sensitivity R eye 18 cpd	51	13.8 ± 11.0	287	18.0 ± 13.9
Psychomotor function				
Tapping PR	51	88.3 ± 13.9	284	79.4 ± 14.7
Tapping NP	51	80.0 ± 10.9	284	72.3 ± 12.8
Tapping alternating	50	46.8 ± 15.1	284	39.9 ± 15.6
Santa Ana PR	51	19.9 ± 3.04	287	18.0 ± 3.49
Santa Ana NP	51	18.0 ± 2.88	285	17.4 ± 3.03
Motor function				
Grip strength	51	32.6 ± 9.61	287	33.8 ± 10.7
Balance				
Postural sway length CON 1	51	37.0 ± 5.66	285	37.7 ± 6.04
Postural sway length CON 2	51	48.2 ± 12.3	285	51.9 ± 13.6
Postural sway length CON 3	51	48.0 ± 9.17	285	48.5 ± 9.69
Postural sway length CON 4	51	75.4 ± 27.1	285	78.8 ± 23.1
Postural sway area CON 1	51	2.78 ± 1.70	285	2.31 ± 1.44
Postural sway area CON 2	51	3.68 ± 2.48	285	3.85 ± 2.55
Postural sway area CON 3	51	4.63 ± 1.99	285	4.59 ± 2.65
Postural sway area CON 4	51	10.1 ± 9.54	285	9.44 ± 4.99

Abbreviations: CON, condition; cpd, cycles per degree; L, left; NP, nonpreferred hand; PR, preferred hand; R, right.
[a]Data for one or more individuals were missing for each test.

shown). Farmworkers had smoked less than controls but had consumed more alcoholic drinks per week. Visual acuity (measured with workers wearing glasses) was slightly better in farmworkers than controls. Farmworkers were less likely than controls to have experienced one or more severe head injuries or to have pain in the nonpreferred hand.

Neurobehavioral test measures. Mean values for test measures (Table 2) in this population were within previously reported ranges (Anger et al. 1993). Test measures were related in the expected directions to all covariates tested: age, sex, education, acculturation, alcohol use, height, weight, head injury, sleep, hand pain, and visual acuity (Table 3).

History of farm work. The entire group of farmworkers had done farm work for an average of 15.9 years (Table 4). Citrus workers and fern workers had worked for more years than nursery workers (means of 18.5, 17.7, and 15.3 years, respectively). More fern workers than nursery or citrus workers had done farm work in the year before testing. There was considerable overlap in the types of farm work participants had done: 44% of fern workers, 73% of nursery workers, and 83% of citrus workers had worked in one or both of the other two types of agriculture. Total years of farm work was weakly correlated with months of fern work ($r = 0.23$), nursery work ($r = 0.10$), and citrus work ($r = 0.31$). Months of fern work was inversely correlated with months of nursery work ($r = –0.34$) and citrus work ($r = –0.29$). Nursery and citrus work were not related ($r = 0.01$).

Association of farm work with neurobehavioral performance. Ever having done any type of farm work or any one of the three particular types (Table 5) was associated with worse performance for digit span forward; for tapping using either hand; for Santa Ana in the preferred hand; and for postural sway length in conditions 2 and 4. There was a small increase in vibrotactile threshold restricted to the index finger of the preferred hand. There was little relationship of farm work to symbol digit latency, visual contrast sensitivity, or grip strength. When present, associations with farm work were comparable in magnitude with associations with most covariates (compare Tables 3 and 5).

For some tests, farmworkers who had done farm work in the year before testing (current farmworkers) had greater deficits than those who had not (former farmworkers), when each group was compared with controls (data not shown). However, current and former farmworkers also differed in several respects other than having done farm work in the previous year. For example, current and former farmworkers had done farm work for an average of 18 versus 10 years and fern work for 75 versus 12 months, respectively, although differences in nursery and citrus work were minor. Values for most covariates

Table 3. Base models for neurobehavioral test measures.[a]

Measure,[b] covariate	Estimate (95% CI)
Digit span forward	
Education, per year	0.78 (0.73 to 0.82)
Acculturation, moderate	0.76 (0.46 to 1.27)
Acculturation, high	0.84 (0.45 to 1.57)
Symbol digit latency	
Age, per 10 years	221 (98 to 344)
Education, per year	–97 (–119 to –75)
Acculturation, moderate	–229 (–434 to –24)
Acculturation, high	–323 (–570 to –76)
Usual sleep, ≥ 7 hrs	–354 (–565 to –143)
Severe head injury, ever	286 (–26 to 599)
Vibrotactile threshold, PR digit 1	
Age, per 10 years	0.05 (0.00 to 0.10)
Sex, female	0.07 (–0.02 to 0.16)
Height, per inch	0.01 (–0.00 to 0.02)
Visual contrast sensitivity, L eye 6 cpd	
Age, 33–37 years	6.29 (–10.0 to 22.6)
Age, 38–43 years	14.8 (–1.57 to 31.3)
Age, 44–55 years	22.0 (4.37 to 39.6)
Sex, female	26.4 (14.4 to 38.5)
Visual acuity L eye, not 20/20	24.1 (11.1 to 37.0)
Tapping PR	
Sex, female	11.5 (8.77 to 14.3)
Education, per year	–1.34 (–1.63 to –1.05)
Santa Ana PR	
Age, per 10 years	1.21 (0.71 to 1.72)
Education, per year	–0.21 (–0.28 to –0.14)
Severe head injury, ever	1.72 (0.41 to 3.04)
Grip strength	
Age, per 10 years	1.48 (0.45 to 2.51)
Sex, female	9.74 (7.90 to 11.6)
Height, per inch	–1.15 (–1.42 to –0.88)
Hand pain	2.68 (0.80 to 4.55)
Postural sway, length CON 4	
Age, 33–37 years	–2.52 (–9.40 to 4.37)
Age, 38–43 years	–1.59 (–8.53 to 5.36)
Age, 44–55 years	6.78 (–0.59 to 14.2)
Height, per inch	1.31 (0.50 to 2.13)
Weight, per 10 pounds	–1.33 (–2.15 to –0.51)
Alcohol drinks per week, 1–14	–1.55 (–7.38 to 4.29)
Alcohol drinks per week, > 14	10.8 (3.11 to 18.5)

Abbreviations: CON, condition; cpd, cycles per degree; L, left; NP, nonpreferred hand; PR, preferred hand; R, right.
[a]Results are ORs (95% CIs) for digit span and coefficients (95% CIs) for other tests; the referent value is 1 for digit span and 0 for other tests. Models for particular test measures included all variables listed. In all cases, a higher value indicates worse performance.
[b]The same covariates were included in the base models for each measure of a test.

Table 4. History of farm work in fern, nursery, and citrus workers.[a]

Characteristics	All farmworkers ($n = 288$)	Fern workers ($n = 140$)	Nursery workers ($n = 147$)	Citrus workers ($n = 141$)
Farm work (years)				
1–9	26	15	31	19
10–20	50	55	46	43
21–41	25	30	22	38
Farm work in previous year				
No	26	15	35	30
Yes	74	85	65	70
Farm work before age 14				
No	84	86	78	78
Yes	16	14	22	22
Migrant farm work (years)				
0	60	71	53	28
1–5	20	17	22	33
> 5	20	12	25	39
Fern work (months)				
No fern work	51	—	76	68
≤ 100	15	30	16	15
100–140	16	34	4	5
> 140	18	36	3	12
Lifetime bunches of ferns cut				
No fern work	51	—	76	68
≤ 350,000	17	35	15	16
350,001–600,000	16	34	5	6
> 600,000	15	31	4	11
Nursery work (months)				
No nursery work	49	75	—	35
≤ 10	16	9	32	21
11–48	16	11	32	23
> 48	18	6	36	21
Citrus work (months)				
No citrus work	51	68	38	—
≤ 9	17	14	22	35
10–42	16	11	23	33
> 42	15	8	16	31

[a]Table entries are column percentages. Controls, who had done farm work for less than 1 month, are not included in the table. Fern, nursery, and citrus workers were defined as those who had worked more than 1 month in the specific type of agriculture. Many farmworkers had worked on more than one crop, so the sum of fern, nursery, and citrus workers is greater than the total number of farmworkers.

for former farmworkers were intermediate between controls and current farmworkers. Specifically, former farmworkers were more educated, more acculturated, and more likely to be female than were current farmworkers (data not shown).

No consistent relationship was found between any neurobehavioral test and having done farm work before age 14, ever having done migrant farm work, or years of doing migrant work (data not shown).

Quantitative measures of farm work and neurobehavioral performance. The three tests that were not related to ever having done farm work (symbol digit latency, visual contrast sensitivity, and grip strength) were also not related to quantitative measures of farm work. For the other five tests, results are presented for one measure of each test that was related to farm work (Table 6). For digit span, tapping, and postural sway, results were generally similar although attenuated for other measures. For vibrotactile threshold and Santa Ana, there was little relation of other measures to farm work.

An increase in lifetime years of farm work was associated with worse performance for digit span, vibrotactile threshold, tapping, and Santa Ana that was monotonically related to work duration with significant trends. There was a tendency for worse performance for postural sway with increasing years of farm work, but estimates were imprecise. Results were similar when the analysis was restricted to participants with at least 6 years of education. After stratification by farm work in the year before testing, performance was related to work duration in both current and former farmworkers.

Lifetime fern work was quantified either as months worked or bunches of ferns cut; the two measures were highly correlated (r = 0.78). Months of fern work was associated with impaired performance for digit span and postural sway that was most pronounced at shorter work durations; with an increase in vibrotactile threshold that was not related to work duration; and with decrements in performance for tapping and Santa Ana that increased with work duration. Results were generally similar using bunches of ferns cut as the exposure measure, although tapping and Santa Ana were not as clearly related to work duration using this measure. Lifetime months of nursery work was associated with decreased performance for digit span, tapping, Santa Ana, and postural sway. Although relationships were not monotonic, the most pronounced effects were seen at the longest work duration. Lifetime months of citrus work was associated with impaired performance for Santa Ana and postural sway. In models including variables for months of all three types of farm work together, associations with fern and nursery work were similar but associations with citrus work were attenuated.

Results were similar when we excluded from the analysis individuals in the following groups (one group at a time): those who had eight or more errors for symbol digit latency or 13 or more errors for tapping (n = 16); those who had consumed an alcoholic beverage in the 7 hr preceding testing (n = 9); those who had used prescription medications potentially affecting neurobehavioral performance (antipsychotics, antidepressants, or antihistamines) in the 24 hr preceding testing (n = 18); those who did not wear their usual glasses during testing (n = 15); those who were not feeling well on the day of the test (n = 6); those who had ever had two or more severe head injuries (n = 6); those who had ever had two or more neck or back injuries (n = 15); those

Table 5. Association of neurobehavioral performance with ever having done farm work.[a]

Test measure	Ever farm work	Ever fern work	Ever nursery work	Ever citrus work
Cognitive function				
Digit span forward	1.90 (1.02 to 3.53)**	2.54 (1.29 to 5.03)***	1.84 (0.9 to 3.51)*	1.79 (0.92 to 3.46)*
Digit span reverse	1.28 (0.70 to 2.33)	1.45 (0.76 to 2.80)	1.21 (0.65 to 2.25)	1.36 (0.72 to 2.58)
Symbol digit latency	–88.0 (–341 to 165)	33.4 (–243 to 309)	–148 (–409 to 112)	–132 (–399 to 135)
Sensory function				
Vibrotactile threshold PR digit 1	0.08 (–0.02 to 0.17)	0.11 (0.00 to 0.21)**	0.06 (–0.04 to 0.16)	0.07 (–0.03 to 0.18)
Vibrotactile threshold PR digit 4	0.00 (–0.09 to 0.09)	0.02 (–0.08 to 0.12)	0.00 (–0.10 to 0.10)	–0.01 (–0.11 to 0.09)
Vibrotactile threshold NP digit 1	–0.02 (–0.11 to 0.07)	–0.02 (–0.11 to 0.08)	–0.02 (–0.11 to 0.07)	–0.04 (–0.14 to 0.05)
Vibrotactile threshold NP digit 4	0.01 (–0.08 to 0.10)	0.04 (–0.06 to 0.14)	0.00 (–0.09 to 0.09)	–0.02 (–0.11 to 0.08)
Contrast sensitivity L eye 1.5 cpd	2.52 (–1.70 to 6.73)	2.57 (–1.98 to 7.12)	2.98 (–1.50 to 7.47)	2.93 (–1.62 to 7.48)
Contrast sensitivity L eye 3 cpd	3.12 (–4.76 to 11.0)	3.17 (–5.33 to 11.7)	3.90 (–4.48 to 12.3)	1.76 (–6.75 to 10.3)
Contrast sensitivity L eye 6 cpd	4.34 (–12.2 to 20.9)	1.74 (–16.1 to 19.6)	3.99 (–13.7 to 21.6)	7.00 (–10.9 to 24.9)
Contrast sensitivity L eye 12 cpd	0.70 (–8.89 to 10.3)	1.36 (–8.99 to 11.7)	0.51 (–9.70 to 10.7)	2.39 (–7.97 to 12.7)
Contrast sensitivity L eye 18 cpd	1.53 (–1.77 to 4.84)	0.88 (–2.68 to 4.45)	2.28 (–1.23 to 5.79)	1.87 (–1.70 to 5.44)
Contrast sensitivity R eye 1.5 cpd	–0.94 (–5.92 to 4.05)	–0.16 (–5.54 to 5.21)	–0.91 (–6.21 to 4.39)	–1.66 (–7.04 to 3.72)
Contrast sensitivity R eye 3 cpd	3.87 (–3.76 to 11.5)	4.66 (–3.58 to 12.9)	4.07 (–4.06 to 12.2)	3.29 (–4.96 to 11.5)
Contrast sensitivity R eye 6 cpd	1.16 (–13.1 to 15.4)	2.03 (–13.4 to 17.4)	1.52 (–13.7 to 16.7)	1.17 (–14.3 to 16.6)
Contrast sensitivity R eye 12 cpd	–5.97 (–15.3 to 3.36)	–8.01 (–18.1 to 2.05)	–3.34 (–13.2 to 6.56)	–6.13 (–16.2 to 3.96)
Contrast sensitivity R eye 18 cpd	–2.72 (–6.25 to 0.80)	–3.24 (–7.05 to 0.56)*	–1.55 (–5.28 to 2.19)	–1.89 (–5.69 to 1.91)
Psychomotor function				
Tapping PR	4.13 (0.00 to 8.27)*	5.38 (0.87 to 9.89)**	3.60 (–0.70 to 7.91)	3.45 (–0.98 to 7.87)
Tapping NP	3.81 (0.26 to 7.35)**	4.85 (0.98 to 8.71)**	3.00 (–0.68 to 6.68)	2.96 (–0.83 to 6.75)
Tapping alternating	2.34 (–2.49 to 7.17)	2.57 (–2.70 to 7.85)	1.59 (–3.44 to 6.61)	1.81 (–3.36 to 6.97)
Santa Ana PR	1.34 (0.29 to 2.39)**	2.29 (1.17 to 3.41)***	0.89 (–0.18 to 1.96)	1.12 (0.00 to 2.23)**
Santa Ana NP	–0.12 (–1.05 to 0.81)	0.69 (–0.31 to 1.68)	–0.41 (–1.37 to 0.54)	–0.62 (–1.59 to 0.36)
Grip strength	–0.46 (–2.49 to 1.57)	0.41 (–1.78 to 2.60)	–0.81 (–2.95 to 1.34)	–0.99 (–3.17 to 1.19)
Balance				
Postural sway length CON 1	0.98 (–0.74 to 2.70)	0.59 (–1.26 to 2.44)	1.46 (–0.37 to 3.29)	1.53 (–0.30 to 3.37)
Postural sway length CON 2	3.86 (–0.15 to 7.88)*	5.95 (1.66 to 10.2)***	3.56 (–0.72 to 7.84)	4.50 (0.21 to 8.79)**
Postural sway length CON 3	1.31(–1.40 to 4.03)	–0.76 (–3.62 to 2.11)	3.11 (0.28 to 5.95)**	2.80 (–0.07 to 5.67)*
Postural sway length CON 4	4.74 (–2.20 to 11.7)	5.94 (–1.53 to 13.4)	6.55 (–0.83 to 13.9)*	7.42 (0.04 to 14.8)**
Postural sway area CON 1	–0.39 (–0.83 to 0.06)*	–0.65 (–1.12 to –0.17)***	–0.18 (–0.65 to 0.29)	–0.24 (–0.71 to 0.24)
Postural sway area CON 2	0.18 (–0.57 to 0.92)	0.28 (–0.52 to 1.09)	0.20 (–0.60 to 1.00)	0.36 (–0.44 to 1.16)
Postural sway area CON 3	0.09 (–0.69 to 0.87)	–0.50 (–1.32 to 0.33)	0.37 (–0.46 to 1.20)	0.42 (–0.41 to 1.25)
Postural sway area CON 4	–0.38 (–2.18 to 1.42)	–0.26 (–2.20 to 1.68)	–0.12 (–2.04 to 1.80)	0.30 (–1.61 to 2.22)

Abbreviations: CON, condition; cpd, cycles per degree; L, left; NP, nonpreferred hand; PR, preferred hand; R, right. [a]Results are ORs (95% CIs) for digit span and coefficients (95% CIs) for other tests. Farm work exposure variables were added individually to the models shown in Table 3. Models for fern, nursery, and citrus work were adjusted for ever having done other types of farm work. The referent for all comparisons is the control group; the value is 1 for digit span and 0 for other tests. In all cases, a higher value indicates worse performance. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

who had ever done work involving exposure to neurotoxicants other than pesticides (n = 34); those who had done such work in the last 2 months (n = 16); and those who reported ever having had an acute toxic reaction to pesticides (n = 19).

Discussion

The results of this study suggest that doing farm work is associated with deficits in neurobehavioral performance. Most previous studies of farmworkers or greenhouse workers have found some evidence of job-related deficits in neurobehavioral performance or increases in neurologic symptoms (Bazylewicz-Walczak et al. 1999; Ciesielski et al 1994; Gomes et al. 1999; McConnell et al. 1994; Rohlman et al. 2001; Rosenstock et al. 1991; Wesseling et al. 2002). However, the observed changes were often small, with some inconsistencies in the specific neurologic defects that were observed. Our study extends previous findings by demonstrating farm work–related neurologic deficits in a large, population-based study that compared workers in different types of agriculture. Farm work in general and fern work in particular were associated with decreased performance, and longer duration of general farm work was associated with worse performance.

Previous studies of neurobehavioral performance in farmworkers have generally assumed that observed deficits are a result of pesticide exposure. Pesticide applicators, including commercial applicators, sheep dippers, and farmers, have also been studied, as have individuals with a history of pesticide poisoning. Acute pesticide poisoning is followed, sometimes after many years, by impaired neurobehavioral performance and decreased nerve conduction velocity as well as increased frequency of neurologic symptoms (London et al. 1998; McConnell et al. 1994; Rosenstock et al. 1991; Savage et al. 1988; Steenland et al. 1994; Wesseling et al. 2002). Chronic pesticide exposure has also been associated with neurologic deficits (Farahat et al. 2003; London et al. 1997; Pilkington et al. 2001; Ruijten et al. 1994; Sack et al. 1993;

Table 6. Association of quantitative measures of farm work with neurobehavioral performance.[a]

Characteristics	Digit span forward	Vibrotactile threshold, PR digit 1	Tapping PR	Santa Ana PR	Postural sway, length CON 4
Years of farm work					
1–9	1.66 (0.83 to 3.34)	0.00 (–0.11 to 0.12)	3.01 (–1.64 to 7.66)	0.71 (–0.46 to 1.88)	3.07 (–5.29 to 11.4)
10–20	2.01 (1.03 to 3.92)**	0.08 (–0.02 to 0.19)	4.26 (–0.18 to 8.71)*	1.45 (0.32 to 2.58)**	4.46 (–3.14 to 12.1)
21–41	2.31 (1.07 to 4.98)**	0.17 (0.05 to 0.28)***	7.08 (1.86 to 12.3)***	2.26 (0.98 to 3.53)***	6.59 (–1.80 to 15.0)
Trend	p = 0.04	p = 0.002	p = 0.009	p = 0.0002	p = 0.11
Years of farm work, participants with 6 or more years of education					
1–9	1.73 (0.80 to 3.78)	0.00 (–0.13 to 0.12)	2.49 (–3.03 to 8.01)	0.33 (–0.99 to 1.65)	3.34 (–6.92 to 13.6)
10–20	2.72 (1.25 to 5.91)**	0.11 (–0.01 to 0.23) *	4.56 (–0.89 to 10.0)	1.72 (0.40 to 3.04)**	6.28 (–3.50 to 16.1)
21–41	4.33 (1.66 to 11.3)***	0.18 (0.02 to 0.33) **	8.88 (2.13 to 15.6) **	2.55 (0.94 to 4.16)***	14.4 (1.94 to 26.8)**
Trend	p = 0.001	p = 0.0007	p = 0.02	p = 0.0002	p = 0.06
Years of farm work, stratified by current or former farm work[b]					
Former, 1–9 years	1.74 (0.80 to 3.82)	–0.04 (–0.16 to 0.09)	1.81 (–3.43 to 7.04)	–0.08 (–1.39 to 1.22)	1.03 (–8.45 to 10.5)
Former, 10–41 years	2.63 (1.11 to 6.25)**	0.01 (–0.13 to 0.14)	3.53 (–2.18 to 9.23)	1.43 (0.02 to 2.83)**	10.8 (0.82 to 20.8)**
Current, 1–9 years	1.48 (0.61 to 3.60)	0.06 (–0.08 to 0.20)	4.92 (–0.96 to 10.8)	1.96 (0.50 to 3.42)***	5.83 (–4.62 to 16.3)
Current, 10–20 years	1.88 (0.93 to 3.79)*	0.12 (0.01 to 0.23)**	5.07 (0.40 to 9.74)**	1.71 (0.54 to 2.89)***	3.06 (–4.82 to 10.9)
Current, 21–41 years	1.99 (0.91 to 4.36)*	0.16 (0.04 to 0.28)***	6.91 (1.59 to 12.2)**	2.45 (1.16 to 3.73)***	5.75 (–2.70 to 14.2)
Months of fern work					
Other farm work only	1.58 (0.83 to 3.00)	0.05 (–0.05 to 0.15)	3.42 (–0.86 to 7.71)	0.76 (–0.31 to 1.82)	3.57 (–3.83 to 11.0)
≤ 100	3.52 (1.53 to 8.11)***	0.14 (0.00 to 0.27)**	2.85 (–2.62 to 8.32)	1.72 (0.38 to 3.07) **	8.49 (–0.94 to 17.9)*
101–140	2.62 (1.14 to 6.01)**	0.07 (–0.06 to 0.20)	5.55 (0.06 to 11.0)**	2.41 (1.04 to 3.77)***	8.82 (–0.42 to 18.1)*
> 140	1.80 (0.81 to 4.02)	0.11 (–0.01 to 0.24)*	7.54 (2.26 to 12.8)***	2.74 (1.43 to 4.05)***	1.02 (–8.04 to 10.1)
Bunches of ferns cut					
Other farm work only	1.60 (0.84 to 3.04)	0.05 (–0.05 to 0.15)	3.32 (–0.96 to 7.60)	0.73 (–0.33 to 1.79)	3.58 (–3.82 to 11.0)
≤ 350,000	3.56 (1.57 to 8.09)***	0.12 (0.00 to 0.25)*	5.84 (0.46 to 11.2)**	1.56 (0.25 to 2.87)**	9.53 (0.40 to 18.7)**
350,001–600,000	2.97 (1.31 to 6.74)***	0.09 (–0.04 to 0.22)	2.66 (–2.73 to 8.04)	2.89 (1.56 to 4.21)***	6.91 (–2.35 to 16.2)
> 600,000	1.60 (0.71 to 3.64)	0.10 (–0.03 to 0.24)	7.74 (2.29 to 13.2)***	2.48 (1.13 to 3.84)***	0.93 (–8.43 to 10.3)
Months of nursery work					
Other farm work only	1.98 (1.00 to 3.92)**	0.10 (–0.01 to 0.20)*	4.88 (0.37 to 9.40)**	2.07 (0.93 to 3.20)***	2.70 (–4.80 to 10.2)
≤ 10	1.93 (0.86 to 4.30)	0.07 (–0.05 to 0.20)	3.62 (–1.73 to 8.96)	0.59 (–0.73 to 1.91)	6.38 (–2.77 to 15.5)
11–48	1.10 (0.50 to 2.38)	0.07 (–0.06 to 0.20)	1.85 (–3.40 to 7.10)	0.42 (–0.88 to 1.72)	2.96 (–6.21 to 12.1)
> 48	2.75 (1.28 to 5.91)***	0.04 (–0.09 to 0.16)	5.04 (0.00 to 10.1)*	1.52 (0.27 to 2.77)**	9.94 (0.97 to 18.9)**
Months of citrus work					
Other farm work only	2.02 (1.04 to 3.90)**	0.08 (–0.02 to 0.18)	4.74 (0.36 to 9.12)**	1.56 (0.45 to 2.68)***	1.84 (–5.64 to 9.32)
≤ 9	1.81 (0.83 to 3.98)	0.07 (–0.06 to 0.19)	4.02 (–1.28 to 9.32)	1.31 (0.00 to 2.62)**	7.94 (–1.00 to 16.9)*
10–42	1.93 (0.87 to 4.28)	0.10 (–0.03 to 0.23)	2.73 (–2.58 to 8.04)	1.40 (0.06 to 2.74)**	7.56 (–1.63 to 16.8)
> 42	1.59 (0.70 to 3.60)	0.05 (–0.08 to 0.18)	3.61 (–1.83 to 9.06)	0.57 (–0.79 to 1.93)	6.64 (–2.75 to 16.0)
Months of fern, nursery, or citrus work					
Other farm work only	0.7 (0.24 to 2.43)	0.24 (0.05 to 0.43)**	3.72 (–4.01 to 11.4)	–0.01 (–1.90 to 1.88)	5.44 (–8.41 to 19.3)
Fern ≤ 100	2.88 (1.46 to 5.67)***	0.11 (0.00 to 0.22)**	0.85 (–3.57 to 5.27)	1.28 (0.20 to 2.35)**	7.00 (–0.72 to 14.7)*
Fern 101–140	2.00 (0.99 to 4.02)*	0.06 (–0.05 to 0.17)	4.18 (–0.48 to 8.85)*	1.87 (0.72 to 3.01)***	10.4 (2.44 to 18.3)**
Fern ≥ 140	1.41 (0.72 to 2.76)	0.10 (–0.01 to 0.21)*	6.33 (1.91 to 10.8)***	2.17 (1.09 to 3.25)***	1.85 (–5.92 to 9.61)
Nursery ≤ 10	1.26 (0.65 to 2.47)	0.02 (–0.08 to 0.13)	1.81 (–2.67 to 6.28)	–0.44 (–1.52 to 0.64)	3.95 (–3.94 to 11.8)
Nursery 11–48	0.63 (0.32 to 1.24)	0.01 (–0.10 to 0.12)	0.38 (–4.18 to 4.93)	–0.73 (–1.83 to 0.36)	–0.18 (–8.22 to 7.86)
Nursery ≥ 48	1.98 (1.03 to 3.81)**	0.00 (–0.11 to 0.11)	3.94 (–0.38 to 8.27)*	0.62 (–0.43 to 1.67)	8.50 (0.69 to 16.3)**
Citrus ≤ 9	1.13 (0.59 to 2.13)	0.02 (–0.09 to 0.13)	0.60 (–3.73 to 4.93)	0.49 (–0.54 to 1.51)	6.59 (–0.90 to 14.1)*
Citrus 10–42	1.13 (0.59 to 2.18)	0.06 (–0.04 to 0.17)	–0.46 (–4.82 to 3.90)	0.65 (–0.41 to 1.71)	6.10 (–1.66 to 13.9)
Citrus ≥ 42	1.08 (0.55 to 2.12)	0.02 (–0.09 to 0.13)	1.44 (–2.99 to 5.88)	0.11 (–0.97 to 1.19)	6.70 (–1.14 to 14.5)*

Abbreviations: CON, condition; PR, preferred hand.
[a]Results are ORs (95% CIs) for digit span and coefficients (95% CIs) for other tests. Farm work exposure variables were added to the models shown in Table 3. The referent for all comparisons is the control group; the value is 1 for digit span and 0 for other tests. In all cases, a higher value indicates worse performance. [b]Current farmworkers had done farm work in the year before testing, whereas former farmworkers had not. *p < 0.10; **p < 0.05; ***p < 0.01.

Steenland et al. 2000; Stephens et al. 1995; Stokes et al. 1995; van Wendel de Joode et al. 2001). Most of these studies did not exclude individuals with a history of pesticide poisoning. Several studies in which such individuals were excluded found no relationship of chronic exposure to neurobehavioral performance or nerve conduction velocity (Ames et al. 1995; Engel et al. 1998; Fiedler et al. 1997), but other studies of nonpoisoned individuals have found associations (Stephens et al. 1995; van Wendel de Joode et al. 2001). We found that farm work was related to worse performance even after excluding 19 individuals who had experienced acute toxic reactions to pesticides.

Few previous studies have directly compared the relative contributions of acute and chronic exposure to low levels of pesticides. Two studies of farmworkers engaged in pesticide application found increased symptom prevalence associated with acute but not chronic exposure (London et al. 1998; Ohayo-Mitoko et al. 2000). In contrast, a study of termiticide applicators found that both acute and chronic exposures were associated with limited neurologic dysfunction, including impaired balance and color vision (Dick et al. 2001; Steenland et al. 2000). Occurrence of symptoms in particular individuals after acute exposure may not be related to later development of neurobehavioral deficits after chronic exposure (Stephens et al. 1996). In our study, decreased performance was associated with work duration in former as well as current workers, with the largest decreases seen after 10 or more years of work. Thus, our results suggest that chronic as well as acute exposure is associated with neurobehavioral performance and that duration of farm work may be as important as recency.

The eight neurobehavioral tests were not affected equally by farm work. Overall, one test of cognitive function (digit span), two of psychomotor function (tapping and Santa Ana), and one of balance (postural sway), an integrated sensorimotor function, were most consistently impaired. Associations with one measure of somatosensory function (vibrotactile threshold) were small and imprecise, seen primarily in fern workers, and restricted to the index finger of the preferred hand. This association may be due to repetitive stress injury such as carpal tunnel syndrome in the fern workers, who repetitively use a small clipper to harvest ferns, although the presence of calluses on the affected finger may provide an alternative explanation (McConnell et al. 1994). There was little relationship of farm work to other tests of cognitive (symbol digit latency), sensory (visual contrast sensitivity), or motor (grip strength) function. Some but not all other studies of farm work or pesticide exposure have reported deficits in symbol digit latency, along with deficits in digit span, vibrotactile threshold, tapping, Santa Ana, and postural sway (Gomes et al. 1999; London et al. 1997; McConnell et al. 1994; Rosenstock et al. 1991; Sack et al. 1993; Savage et al. 1988; Steenland et al. 1994, 2000; Stephens et al. 1995; Stokes et al. 1995; Wesseling et al. 2002). Although these results are not completely consistent, it is noteworthy that no study has reported an exposure-related improvement in performance. Variations in type and degree of exposure and methodologic differences, including choice of control group, procedures for administering and scoring neurobehavioral tests, and control for potential confounding, likely account for the differences in findings.

There was considerable overlap among the three types of farm work, with 44–87% of each group having worked in one or both of the other two types of agriculture. Nevertheless, the three types of work varied in their relationships to neurobehavioral performance. Specifically, fern work had a more robust relationship than nursery or citrus work to digit span, tapping, and Santa Ana. Fern workers had done farm work for more years than nursery workers, although not more than citrus workers. They were less educated than were other farmworkers, but they were also younger and less likely to use or have problems with alcohol. Thus, confounding does not appear to account for the stronger association of fern work with neurologic dysfunction. Differences in neurobehavioral performance may be related to differences in pesticide exposure. Relatively few pesticides are used on citrus fruit (McCoy et al. 2003) compared with ferns or nursery plants (Vasquez and Nesheim 2000). Further, fern workers spend a large proportion of their time in intimate contact with treated plants, and may in fact be more heavily exposed to pesticides than are other farmworkers.

Many anthropomorphic, demographic, and lifestyle characteristics are known to affect neurobehavioral performance (Anger et al. 1997; Kilburn et al. 1998; Krieg et al. 2001). We found age, sex, education, acculturation, alcohol use, hours of sleep, head injury, hand pain, height, weight, and visual acuity to be related to one or more of the tests we studied. Our models were adjusted for these characteristics, so confounding is unlikely to fully explain the relationships we observed. Additional reassurance that confounding is not a major determinant of our findings is provided by the finding of associations among former as well as current farmworkers, although former farmworkers were more similar to controls than were current farmworkers. A potential confounder of great concern is education, but our results were unchanged in analyses restricted to individuals with 6 or more years of education. It is also noteworthy that deficits in performance were not restricted to computerized tests, so lack of familiarity with computers does not account for our findings. Analyses excluding individuals whose performance may have been affected by alcohol, medication, illness, injury, or exposure to neurotoxicants other than pesticides suggested that our findings were not heavily influenced by these individuals.

The strengths of our study include its relatively large size, which allowed us to compare workers in three different types of agriculture. We used a defined target population and achieved high response rates (Kamel et al. 2001), reducing potential for selection bias. We collected detailed questionnaire information to account for numerous potential confounders. Limitations of the study include the use of indirect exposure measures and the small number of tests included in our neurobehavioral test battery, which made it difficult to evaluate effects on specific aspects of neurologic function. The study was also limited by the fact that the controls differed from the farmworkers in several important respects, notably education and acculturation.

In conclusion, this study suggests that farm work is associated with deficits in neurologic function, particularly cognitive and psychomotor function. Associations with farm work were similar in magnitude to associations with personal characteristics known to affect neurobehavioral performance, including age, sex, alcohol use, and head injury. Deficits related to the duration of work experience were seen in former as well as current farmworkers, and decreased performance was related to chronic exposure even in the absence of a history of pesticide poisoning. Greater risk was associated with fern work than with other kinds of farm work. Although the absolute differences in performance seen in this and other studies are small, they could nevertheless be important on a population basis, by increasing the proportion of impaired individuals. Neurologic deficits have been observed in studies of farmworkers and other individuals chronically exposed to pesticides. However, farmworkers are exposed to other hazards, including injury, metals, allergens, and soil pathogens. Further work will thus be necessary to determine whether the observed deficits are related to pesticide exposure or to other hazards.

References

Ames R, Steenland K, Jenkins B, Chrislip D, Russo J. 1995. Chronic neurologic sequelae to cholinesterase inhibition among agricultural pesticide applicators. Arch Environ Health 50:440–444.

Anger WK. 2003. Neurobehavioral tests and systems to assess neurotoxic exposure in the workplace and community. Occup Environ Med 60:531–538.

Anger WK, Cassitto MG, Liang YX, Amador R, Hooisma J, Chrislip DW, et al. 1993. Comparison of performance from three continents on the WHO-recommended neurobehavioral core test battery. Environ Res 62:125–147.

Anger WK, Liang YX, Nell V, Kang SK, Cole D, Bazylewicz-Walczak B, et al. 2000. Lessons learned—15 years of the WHO-NCTB: a review. Neurotoxicology 21:837–846.

Anger WK, Sizemore OJ, Grossmann SJ, Glasser JA, Letz R, Bowler R. 1997. Human neurobehavioral research methods: impact of subject variables. Environ Res 73:18–41.

Bazylewicz-Walczak B, Majczakowa W, Szymczak M. 1999. Behavioral effects of occupational exposure to organophosphorous pesticides in female greenhouse planting workers. Neurotoxicology 20:819–826.

Ciesielski S, Loomis DP, Mims SR, Auer A. 1994. Pesticide exposures, cholinesterase depression, and symptoms among North Carolina migrant farmworkers. Am J Publ Health 84:446–451.

Das R, Steege A, Baron S, Beckman J, Harrison R. 2001. Pesticide-related illness among migrant farm workers in the United States. Int J Occup Environ Health 7:303–312.

Dick R, Steenland K, Krieg E, Hines C. 2001. Evaluation of acute sensory-motor effects and test sensitivity using termiticide workers exposed to chlorpyrifos. Neurotoxicol Teratol 23:381–393.

Engel LS, Keifer MC, Checkoway H, Robinson LR, Vaughan TL. 1998. Neurophysiological function in farm workers exposed to organophosphate pesticides. Arch Environ Health 53:7–14.

Farahat TM, Abdelrasoul GM, Amr MM, Shebl MM, Farahat FM, Anger WK. 2003. Neurobehavioral effects among workers occupationally exposed to organophosphorous pesticides. Occup Environ Med 60:279–286.

Farmworkers Health Study. 2003. Farmworkers Health Study Homepage. Research Triangle Park, NC:Epidemiology Branch, National Institute of Environmental Health Sciences. Available: http://dir.niehs.nih.gov/direb/fwhs/home_fwhs.htm [accessed 14 April 2003].

Fiedler N, Kipen H, Kelly-McNeil K, Fenske R. 1997. Long-term use of organophosphates and neuropsychological performance. Am J Ind Med 32:487–496.

Gomes J, Lloyd OL, Revitt DM. 1999. The influence of personal protection, environmental hygiene and exposure to pesticides on the health of immigrant farm workers in a desert country. Int Arch Occup Environ Health 72:40–45.

Kamel F, Moreno T, Rowland AS, Stallone L, Ramirez-Garnica G, Sandler DP. 2001. Recruiting a community sample in collaboration with farmworkers. Environ Health Perspect 109(suppl 3):457–459.

Katz JN, Larson MG, Fossel AH, Liang MH. 1991. Validation of a surveillance case definition of carpal tunnel syndrome. Am J Public Health 81:189–193.

Keifer M, Mahurin R. 1997. Chronic neurologic effects of pesticide overexposure. Occup Med 12:291–304.

Kilburn KH, Thornton JC, Hanscom B. 1998. Population-based prediction equations for neurobehavioral tests. Arch Environ Health 53:257–263.

Krieg E, Chrislip D, Letz R, Otto D, Crespo C, Brightwell W, et al. 2001. Neurobehavioral test performance in the third National Health and Nutrition Examination Survey. Neurotoxicol Teratol 23:569–589.

London L, Myers JE, Nell V, Taylor T, Thompson ML. 1997. An investigation into neurologic and neurobehavioral effects of long-term agrichemical use among deciduous fruit farm workers in the Western Cape, South Africa. Environ Res 73:132–145.

London L, Nell V, Thompson M, Myers J. 1998. Effects of long-term organophosphate exposures on neurological symptoms, vibration sense and tremor among South African farm workers. Scand J Work Environ Health 24:18–29.

McConnell R, Keifer M, Rosenstock L. 1994. Elevated quantitative vibrotactile threshold among workers previously poisoned with methamidophos and other organophosphate pesticides. Am J Ind Med 25:325–334.

McCoy CW, Nigg HN, Timmer LW, Futch SH. 2003. Florida Citrus Pest Management Guide: Use of Pesticides in Citrus IPM. Gainesville, FL:University of Florida Extension. Available: http://edis.ifas.ufl.edu/CG035 [accessed 25 June 2003].

Moses M, Johnson ES, Anger WK, Burse VW, Horstman SW, Jackson RJ, et al. 1993. Environmental equity and pesticide exposure. Toxicol Ind Health 9:913–959.

National Health and Nutrition Examination Survey. 2003. NHANES III Data Files. Atlanta, GA:National Center for Health Statistics. Available: http://www.cdc.gov/nchs/about/major/nhanes/nh3data.htm [accessed 25 June 2003].

Ohayo-Mitoko GJ, Kromhout H, Simwa JM, Boleij JS, Heederik D. 2000. Self reported symptoms and inhibition of acetylcholinesterase activity among Kenyan agricultural workers. Occup Environ Med 57:195–200.

Pilkington A, Buchanan D, Jamal GA, Gillham R, Hansen S, Kidd M, et al. 2001. An epidemiological study of the relations between exposure to organophosphate pesticides and indices of chronic peripheral neuropathy and neuropsychological abnormalities in sheep farmers and dippers. Occup Environ Med 58:702–710.

Rohlman D, Bailey S, Anger W, McCauley L. 2001. Assessment of neurobehavioral function with computerized tests in a population of Hispanic adolescents working in agriculture. Environ Res 85:14–24.

Rohlman DS, Bailey SR, Brown M, Blanock M, Anger WK, McCauley L. 2000a. Establishing stable test performance in tests from the Behavioral Assessment and Research System (BARS). Neurotoxicology 21:715–723.

Rohlman DS, Gimenes LS, Ebbert C, Anger WK, Bailey SR, McCauley L. 2000b. Smiling faces and other rewards: using the Behavioral Assessment and Research System (BARS) with unique populations. Neurotoxicology 21:973–978.

Rohlman DS, Gimenes L, Eckerman DA, Kang SK, Farahat FM, Anger WK. 2003. Development of the Behavioral Assessment and Research System (BARS) to detect and characterize neurotoxicity in humans. Neurotoxicology 24:523–531.

Rosenstock L, Keifer M, Daniell WE, McConnell R, Claypoole K, the Pesticide Health Effects Study Group. 1991. Chronic central nervous system effects of acute organophosphate pesticide intoxication. Lancet 338:223–227.

Ruijten MWMM, Salle HJA, Verberk MM, Smink M. 1994. Effect of chronic mixed pesticide exposure on peripheral and autonomic nerve function. Arch Environ Health 49:188–195.

Sack D, Linz D, Shukla R, Rice C, Bhattacharya A, Suskind R. 1993. Health status of pesticide applicators: postural stability assessments. J Occup Med 35:1196–1202.

Savage EP, Keefe TJ, Mounce LM, Heaton RK, Lewis JA, Burcar PJ. 1988. Chronic neurological sequelae of acute organophosphate pesticide poisoning. Arch Environ Health 43:38–45.

Steenland K, Dick RB, Howell RJ, Chrislip DW, Hines CJ, Reid TM, et al. 2000. Neurologic function among termiticide applicators exposed to chlorpyrifos. Environ Health Perspect 108:293–300.

Steenland K, Jenkins B, Ames RG, O'Malley M, Chrislip D, Russo J. 1994. Chronic neurological sequelae to organophosphate pesticide poisoning. Am J Public Health 84:731–736.

Stephens R, Spurgeon A, Berry H. 1996. Organophosphates: the relationship between chronic and acute exposure effects. Neurotoxicol Teratol 18:449–453.

Stephens R, Spurgeon A, Calvert IA, Beach J, Levy LS, Berry H, et al. 1995. Neuropsychological effects of long-term exposure to organophosphates in sheep dip. Lancet 345:1135–1139.

Stokes L, Stark A, Marshall E, Narang A. 1995. Neurotoxicity among pesticide applicators exposed to organophosphates. Occup Environ Med 52:648–653.

van Wendel de Joode B, Wesseling C, Kromhout H, Monge P, Garcia M, Mergler D. 2001. Chronic nervous-system effects of long-term occupational exposure to DDT. Lancet 357:1014–1016.

Vasquez BCL, Nesheim ON. 2000. Florida Crop/Pest Management Profiles: Ornamentals. Gainesville, FL:University of Florida Extension. Available http://edis.ifas.nfl.edu/P1058 [accessed 25 June 2003].

Villarejo D, Baron S. 1999. The occupational health status of hired farm workers. Occup Med 14:613–635.

Wesseling C, Keifer M, Ahlbom A, McConnell R, Moon J, Rosenstock L, et al. 2002. Long-term neurobehavioral effects of mild poisonings with organophosphate and n-methyl carbamate pesticides among banana workers. Int J Occup Environ Health 8:27–34.