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. Sandler1

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

Farmworkers experience many work-related hazards, including exposure to neurotoxins. 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. Every 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 farm 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, including exposure to neurotoxins. 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. Every 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 farm 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]
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.

### 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 et al. 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 with the index and fourth digits of both hands using an Optec 1000 (Stereo Optical Co, Chicago, IL). Visual contrast sensitivity was

### Table 1. Characteristics of study participants.

| 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                       | 24                    | 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                      |
| 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                      |

*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.
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) were presented. All other test measures were analyzed using linear regression; coefficients and 95% CIs 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 farm, nursery, and citrus work were constructed to evaluate each type of farm work separately from the other types. For example, the ever farm 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 workers 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 farm 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 presented).

Table 2. Neurobehavioral test measures in controls and farmworkers

| Test measures                  | Controls | Farmworkers |
|-------------------------------|----------|-------------|
|                               | No.² | Mean ± SD | No.² | 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   | 2.23 ± 0.74 | 273  | 2.68 ± 0.93 |
| 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 R eye 1.5 cpd | 51   | 16.1 ± 13.4 | 287  | 16.1 ± 12.4 |
| Contrast sensitivity R eye 3 cpd | 51   | 21.1 ± 9.7  | 287  | 23.0 ± 17.7 |
| Contrast sensitivity R eye 6 cpd | 51   | 37.7 ± 33.0 | 287  | 36.3 ± 24.9 |
| Contrast sensitivity R eye 12 cpd | 51   | 63.8 ± 53.3 | 287  | 66.2 ± 51.2 |
| Contrast sensitivity R eye 18 cpd | 51   | 39.9 ± 34.7 | 287  | 50.5 ± 36.0 |
| 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   | 18.9 ± 3.04 | 287  | 18.0 ± 3.49 |
| Santa Ana NP                  | 51   | 18.0 ± 2.89 | 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 | 295  | 2.31 ± 1.44 |
| Postural sway area CON 2      | 51   | 3.68 ± 2.48 | 295  | 3.85 ± 2.55 |
| Postural sway area CON 3      | 51   | 4.63 ± 2.19 | 295  | 4.59 ± 2.05 |
| Postural sway area CON 4      | 51   | 10.1 ± 9.54 | 295  | 9.44 ± 4.99 |

Abbreviations: CON, condition; cpd, cycles per degree; L, left; NP, nonpreferred hand; PR, preferred hand; R, right.

*Data for one or more individuals were missing for each test.
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. Even 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

| Measure | Estimate (95% CI) |
|-----------------|-----------------|
| Digit span forward Education, per year | 0.78 (0.73 to 0.82) |
| Acculturation, moderate | 0.73 (0.64 to 0.82) |
| Age, per 10 years | 221 (98 to 344) |
| Symbol digit latency | 0.84 (0.45 to 1.57) |
| Visual contrast sensitivity, L eye 6 cpd | 0.05 (0.00 to 0.10) |
| Visual acuity L eye, not 20/20 | 0.07 (0.02 to 0.16) |
| Severe head injury, ever | 0.01 (0.00 to 0.02) |
| Tapping PR | 6.29 (−10.0 to 22.6) |
| Grip strength | 14.8 (−1.57 to 31.3) |
| Hand pain | 22.0 (3.47 to 39.6) |
| Postural sway, length CON 4 | 14.8 (−1.57 to 31.3) |
| Weight, per 10 pounds | 6.78 (−0.59 to 14.2) |
| Height, per inch | 1.31 (0.50 to 2.13) |
| Alcohol drinks per week, 1–14 | 1.31 (0.50 to 2.13) |
| Alcohol drinks per week, > 14 | 0.78 (0.73 to 0.82) |

Abbreviations: CON, condition; cpd, cycles per degree; L, left; NP, nonpreferred hand; PR, preferred hand; R, right.

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.

The same covariates were included in the base models for each measure of a test.

| Characteristics | All farmworkers (n = 288) | Farm workers (n = 140) | Nursery workers (n = 147) | Citrus workers (n = 141) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Farm work (years) | | | | |
| < 4 26 15 31 19 |
| 4–10 50 55 46 43 |
| 10–20 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 |
| > 5 20 12 25 39 |
| Farm work (months) | No fern work 51 — 76 68 |
| ≤ 100 15 30 18 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 |

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.

Lifet ime farm work was quantified either as months worked or bunches of ferns cut; the two measures were highly correlated (r = 0.78). Months of farm 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.

| Test measure | Ever farm work | Ever nursery work | Ever citrus work |
|--------------|----------------|------------------|-----------------|
| **Cognitive function** | | | |
| Digit span forward | 1.90 (1.02 to 3.59)** | 2.54 (1.29 to 5.03)** | 1.84 (0.93 to 3.64)** |
| Digit span reverse | 1.28 (0.70 to 2.33) | 1.45 (0.76 to 2.80) | 1.21 (0.65 to 2.25) |
| Symbol digit latency | –88.0 (–341 to 165) | 33.4 (–243 to 309) | –148 (–409 to 112) |
| **Sensory function** | | | |
| Vibrotactile threshold PR digit 1 | 0.08 (–0.32 to 0.17) | 0.11 (0.00 to 0.21)** | 0.06 (–0.04 to 0.16) |
| Vibrotactile threshold PR digit 4 | 0.05 (0.09 to 0.99) | 0.02 (–0.08 to 0.12) | 0.00 (–0.02 to 0.10) |
| Contrast sensitivity R eye 3 cpd | 2.38 (–2.49 to 7.25) | 2.57 (–2.95 to 7.70) | 2.98 (–1.22 to 7.18) |
| Contrast sensitivity L eye 1.5 cpd | 3.12 (–3.67 to 11.10) | 3.17 (–3.53 to 11.93) | 3.90 (–4.48 to 12.23) |
| Tapping NP | 0.97 (–0.89 to 10.30) | 1.36 (–0.99 to 11.7) | 0.51 (–0.97 to 10.7) |
| Tapping PR | 1.53 (–1.77 to 4.84) | 0.80 (–2.68 to 4.45) | 2.28 (–1.23 to 5.79) |
| Contrast sensitivity R eye 1.5 cpd | 3.12 (–2.49 to 7.25) | 2.57 (–2.95 to 7.70) | 2.98 (–1.22 to 7.18) |
| Contrast sensitivity L eye 1.5 cpd | 3.12 (–2.49 to 7.25) | 2.57 (–2.95 to 7.70) | 2.98 (–1.22 to 7.18) |
| Contrast sensitivity R eye 3 cpd | 3.87 (–3.76 to 11.5) | 4.66 (–3.58 to 12.9) | 4.07 (–0.46 to 12.2) |
| Contrast sensitivity L eye 3 cpd | 1.16 (–1.31 to 15.4) | 2.03 (–1.34 to 17.4) | 1.52 (–0.17 to 16.7) |
| 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) |
| Contrast sensitivity L eye 12 cpd | –2.72 (–6.25 to 0.80) | –3.24 (–7.05 to 0.56)* | –1.55 (–5.29 to 2.19) |
| **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) |
| Tapping NP | 3.81 (0.26 to 7.36)** | 4.85 (0.98 to 8.71)** | 3.00 (–0.68 to 6.68) |
| Tapping alternating | 2.34 (–2.49 to 7.17) | 2.57 (–2.70 to 7.85) | 1.59 (–3.44 to 6.61) |
| Santa Ana PR | 1.34 (0.29 to 2.39)** | 2.29 (1.17 to 3.41)*** | 0.89 (–0.18 to 1.96) |
| Santa Ana NP | –0.12 (–0.05 to 0.81) | 0.63 (–0.31 to 1.88) | –0.41 (–1.37 to 0.54) |
| Grip strength | –0.46 (–2.49 to 1.57) | 0.41 (–1.78 to 2.60) | –0.82 (–2.95 to 1.34) |
| **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) |
| Postural sway length CON 2 | 3.86 (–0.15 to 7.88)* | 5.95 (1.66 to 10.21)** | 3.56 (–0.72 to 7.84) |
| Postural sway length CON 3 | 1.31 (–4.40 to 0.43) | –0.76 (–3.62 to 2.11) | 3.11 (0.28 to 5.95)** |
| 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)*** |
| Postural sway area CON 1 | –0.39 (–0.83 to 0.06)* | –0.65 (–1.12 to 0.77)*** | –0.18 (–0.65 to 0.09) |
| Postural sway area CON 2 | 0.18 (0.57 to 0.92) | 0.20 (0.52 to 1.09) | 0.20 (–0.60 to 1.00) |
| Postural sway area CON 3 | 0.69 (–0.69 to 0.97) | 0.50 (–1.32 to 0.33) | 0.37 (–0.46 to 1.20) |
| Postural sway area CON 4 | –0.38 (–2.18 to 1.42) | –0.26 (–2.20 to 1.60) | –0.12 (–2.04 to 1.80) |

Abbreviations: CON, condition; cpd, cycles per degree; L, left; NP, nonpreferred hand; PR, preferred hand; R, right. *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 farm, 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; Rohman 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; a)

### Table 6. Association of quantitative measures of farm work with neurobehavioral performance.

| 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             | 1.41 (0.73 to 2.76) | 0.03 (–0.13 to 0.22)**            | 1.02 (–0.46 to 2.52)**  | 0.09 (–0.37 to 0.55)**  | 0.06 (–0.29 to 0.38)**    |
| 10–20            | 2.31 (1.66 to 3.98)** | 0.18 (0.02 to 0.33)**              | 0.01 (–0.29 to 0.29)**  | 0.00 (–0.33 to 0.33)**  | 0.01 (–0.33 to 0.33)**    |
| **Trend** | 0.0001                   | 0.0001                           | 0.0001     | 0.0001      | 0.0001                    |
| **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 (–0.98 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 (–0.84 to 10.0)  | 1.72 (0.40 to 3.04)**  | 8.28 (–3.51 to 16.5)    |
| **Trend** | 0.0001                   | 0.0001                           | 0.0001     | 0.0001      | 0.0001                    |

**Abbreviations:** CON, condition; PR, preferred hand.

*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. aCurrent farmworkers had done farm work in the year before testing, whereas former farmworkers had not. \(p < 0.10\); \(** p < 0.05\); *** \(p < 0.01\).*
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; Ohayomi et al. 2000). In contrast, a study of termiteicide 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 farm 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 farm 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, 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, Ciasitto MG, Liang YX, Amador R, Hoosma J, Chrislip DW, et al. 1993. Comparison of performance from three continents on the WHD-recommended neurobehavioral core test battery. Environ Res 62:125–147.
Anger WK, Liang YX, Nell V, Kang SK, Cole D, Bayzelywicz-Walczak E, et al. 2000. Lessons learned—15 years of the WHO-NCCT: a review. Neurotoxicology 21:837–866.

Wesseling C, Keifer M, Ahlbom A, McConnell R, Moon J, Rohlman DS, Gimenes L, Ebbert C, 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, Claypole K, the Pesticide Health Effects Study Group. 1991. Chronic central nervous system effects of acute organophosphate pesticide intoxication. Lancet 338:223–227.

Rujten MJWM, 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, Shulka R, Rice C, Bhattacharya A, Suskind R. 1993. Health status of pesticide applicators: postural stability assessments. J Occup Med 35:1196–1202.

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

Steinkind 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.

Steinkind 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, 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, Naranj 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 DN. 2000. Florida Crop/Pest Management Profiles: Ornaminals. Gainesville, FL:University of Florida Extension. Available http://edis.ifas.ufl.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, Altbom 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.