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# Neurobehavioral Performance of Adult and Adolescent Agricultural Workers

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**Abstract**

There are many occupational hazards associated with working in agriculture including risk of injury and exposure to pesticides. Research examining neurobehavioral effects of pesticide exposure have focused primarily on the acute effects in adults working in agriculture. Organophosphate poisoned populations have shown a consistent pattern of deficits when compared to a non-exposed or non-poisoned population on measures of motor speed and coordination, sustained attention, and information processing speed. Fewer studies have examined the effect of long-term low-level exposure on nervous system functioning in agricultural workers. Pesticides are thought to pose a considerably higher risk to children than to adults, yet little is known about the extent or magnitude of health problems related to occupational exposure to pesticides in children and adolescents. The present study compared the neurobehavioral performance of adolescents and adults working in agriculture and examined the impact of years working in agriculture on neurobehavioral performance. One hundred seventy-five Hispanic adolescent and adults completed a neurobehavioral test battery consisting of 10 computer-based tests measuring attention, response speed, coordination and memory. Age, gender, school experience, and years working in agriculture all impacted performance on the neurobehavioral tests. Comparison of adult and adolescents did not reveal decreased neurobehavioral performance in adolescents. On several tests the adolescents performed better than adult counterparts. The adolescents and adults were engaged in comparable agricultural working environments at the time of the neurobehavioral testing. These findings suggest that, at the time of exposure to pesticides, adolescents are not more vulnerable to the effects of working in agriculture. Evidence from this study suggests that cumulative exposure to low levels of pesticides over many years of agricultural work is associated with neurological impairment as measured by the Selective Attention, Symbol-Digit, Reaction Time tests. Experience handling pesticides was also associated with deficits in neurobehavioral performance.


*Keywords:* Neurobehavioral tests; Pesticides; Adolescents; Agriculture; Hispanic

## 1. Introduction

Agricultural work has one of the highest injury rates in the workplace (Arcury and Quandt, 1998a,b). Compounding this problem, agricultural or farm workers are a high-risk group for exposure to chemicals, including pesticides, used in agriculture. Exposure to pesticides has been linked with chronic and acute health effects (Woodruff et al., 1994). Workers come in contact with pesticides through occupational exposure as well as drift from living in housing located near the fields (Loewenherz et al., 1997). Exposure may also occur when pesticides are brought into the home on workers clothing and skin. Because the majority of fruits and vegetables produced in the United States are harvested by hand (Oliveira et al., 1993), exposures may occur during the application of the pesticides or during the cultivation or harvesting of the crop.

The majority of seasonal and migrant agricultural workers in the United States are Hispanic (Mines et al., 1997). Agriculture workers range in age from children in their teens to adults in their 60s (Arcury and Quandt, 1998a,b). Adolescents working

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in agriculture can either be children of seasonal or migrant farmworkers or local youth living in agricultural communities. A third group consists of adolescents who migrate and travel independently from their families. These emancipated minors tend to be young men from Mexico (Gabbard et al., 1999). Adolescent farmworkers have other needs that make them unique from the general farmworker population, including the fact that many are new immigrants to the US and working in agriculture for the first time. Also emancipated minors may be living on their own without adult supervision.

In recent years there has been heightened concern over the potential of occupational or environmental exposures to affect neurological function in children and adolescents. Adolescents who work in agriculture are vulnerable to the same risks of exposures as adult workers. Pesticides are thought to pose a considerably higher risk to children due to behavior (e.g., increased hand-to-mouth activity) and potentially longer-term exposure over a working lifetime, overall higher activity levels and faster metabolism, and smaller body weight per exposure (Meister, 1991). There is also concern about the impact of neurotoxicants on the developing central nervous system (Amler and Gibertini, 1996). During adolescence there are significant anatomical and maturational changes in the brain (Andersen, 2003; Brown et al., 2000; Spear, 2002). However, very little research has examined the impact of neurotoxicants on the central nervous system of adolescents (Adams et al., 2000; Brown et al., 2000; Spear, 2002).

Adolescents are engaged in similar agricultural work tasks as adult workers. Studies of adolescent farmworkers in Oregon have reported that at least 20% of adolescents report mixing and applying pesticides (McCauley et al., 2004, 2002). Further, little is known about the extent or magnitude of health problems related to occupational exposure to pesticides in children and adolescents. Environmental exposures and health effects in children have been poorly characterized. Even less scientific evidence is available to identify adverse effects of pesticide exposure in children as a basis for risk assessment.

### 1.1. Pesticides and neurobehavioral performance

Deficits on measures of motor speed and coordination, including latency and response speed measures, have been reported in organophosphate (OP) pesticide poisoned adult populations tested after recovery (Reidy et al., 1992; Rosenstock et al., 1991; Savage et al., 1988; Steenland et al., 1994) and in different occupational workers chronically exposed to pesticides (Bazylewicz-Walczak et al., 1999; Kamel et al., 2003; Rohlman et al., 2001a,b; Roldán-Tapia et al., 2005; Stephens et al., 1995). A broad range of deficits (including visual motor speed, verbal abstraction, attention, and memory) was found in adult cotton pesticide applicators in Egypt (Farahat et al., 2003).

There is little research on the effects of OP pesticides on children. Using versions of some of the same tests employed in the current study, Rohlman et al. (2001b) found deficits on tests of cognitive functioning and reaction time in adolescents aged 13–18 working in agriculture as compared to adolescents not working in agriculture. Measuring growth and development, differences in preschool children presumably exposed to pesticides were found when compared to children less-exposed (Guillette et al., 1998). Although there were no differences in growth patterns, the exposed children showed deficits in hand-eye coordination, memory and ability to draw a person. Preschool children whose parents were currently working in agriculture had significantly poorer performance on measures of response speed and latency than children with parents not working in agriculture (Rohlman et al., 2005). School-age children in Ecuador whose mother's were occupationally exposed to pesticides during pregnancy had increased blood pressure and reduced performance on a visuospatial task, a copying task, compared to controls (Grandjean et al., 2006). In addition urinary metabolites, reflecting a current measure of exposure, were associated with increased Simple Reaction Time.

A study comparing health effects, biomarkers of exposure, and neurobehavioral performance between Hispanic adolescents and adults currently working in agriculture and adolescents and adults not currently working in agriculture was conducted. In this paper we present the results of the comparison of neurobehavioral performance among the different study populations and the influence of age, gender, school experience and years working in agriculture on test performance. The impact of self-reported pesticide use on neurobehavioral performance was also reported.

## 2. Methods

### 2.1. Participants

During the summer of 2004, 119 Hispanic adults and adolescents currently working in agriculture (AG) and 56 Hispanic adolescents and adults not currently working in agriculture (non-AG) completed the neurobehavioral test battery. Participants were recruited from Hispanic communities in Oregon through ESL (English as a Second Language) classes, labor camps, and Migrant Education programs. Farmworker participants were currently working as field workers and comparison groups had not worked in the farm fields for at least 1 year, but may have had a history of agricultural work. People working in landscaping or plant nurseries were excluded from the study. An adolescent was defined as an individual between 12 and 18 years of age. An adult was defined as an individual between 19 and 60 years of age.

The majority of participants were immigrants from Mexico, primarily from the state of Oaxaca. Nine participants were born in the United States. Sixty-seven participants listed an indigenous dialect as their primary language. Participants were excluded from the study if they did not speak Spanish or English.

### 2.2. Procedures

Participants completed a Spanish-language consent form that was explained to the participants. Participants then completed tests from a neurobehavioral test battery and an interview with an Examiner fluent in Spanish and English. Biological samples for analysis of biomarkers of exposure to pesticides and DNA damage were also collected and analysis is currently in progress and not the focus of this paper. The interview was administered one-on-one and consisted of questions regarding demographic information, health, work practices and home hygiene questions. The neurobehavioral test battery was administered to each participant on a computer. Between six and eight participants were working at any time, with an examiner fluent in Spanish and English present to answer questions.

### 2.3. Neurobehavioral battery

The Behavioral Assessment and Research System (BARS) was developed for use with a broad range of working populations having varied education levels and cultural backgrounds (Anger et al., 1996; Rohlman et al., 2003), including children (Rohlman et al., 2000, 2001a,b). Features of the BARS that enable this broad application include: simple language instructions broken down into basic concepts (step-by-step training with competency testing at each instruction step); a ‘‘smiling face’’ used to reinforce performance; and adjustable parameter settings (Rohlman et al., 1996). A durable response unit with nine response buttons is placed over a keyboard (Rohlman et al., 2003) to minimize the impact of working on a potentially intimidating device such as a computer keyboard. The BARS tests presented in Table 1 were selected, based on previous evidence of effects of pesticides on the functions tested (Rohlman et al., 2000, 2001a,b).

### 2.4. Statistical analysis

Neurobehavioral performance measures and demographic variables such as age and education were summarized using means and standard deviations; dichotomous or discrete multi-level data were summarized with proportions. Multiple regression was applied separately to each neurobehavioral test measure to assess the effect of years working in agriculture (greater years assumed to produce worse performance). One-sided $p$-values were used to test the hypothesis that adolescents working in agricultural would have decreased neurobehavioral performance when compared to their adult counterparts. The continuous covariates of age, years of education in the participant’s country of origin, and years spent working in agriculture were entered into the models assessing the differences in adolescent and adult farmworkers. Gender was added to the models if performance differed between the sexes or if linear trends for one or more of the factors was modified (through an interaction) by sex. Agricultural status was not used in the models because many of the non-AG participants were found to have spent at least 2 years working in agriculture. Participants with incomplete data on a neurobehavioral performance test were excluded from the analysis of that test.

Table 1
Neurobehavioral tests, outcome measures and functions being tested in the battery

| Neurobehavioral test (outcome measure) | Function |
|---|---|
| Finger Tapping (number of taps) | Response speed, coordination |
| Symbol-Digit (latency) | Coding, complex functioning |
| Simple Reaction Time (latency) | Response speed |
| Digit Span (correct score) | Attention, memory |
| Progressive Ratio (number of taps) | Motivation |
| Selective Attention (number of trials, latency) | Sustained attention |
| Serial Digit Learning (score) | Learning |
| Continuous Performance (percent hits, percent false alarms, percent omissions, d-prime) | Attention |
| Match-to-Sample (score, latency) | Visual memory |
| Reversal Learning (trials to criterion) | Learning |

## 3. Results

A total of 175 individuals completed the neurobehavioral test battery (Table 2). Seventy-two percent of the non-AG adults and 37% of the non-AG adolescents report working in agriculture in the past. In fact, five non-AG participants had at least 8 years of agricultural experience with two reporting 10 years and one reporting 14 years.

Thirty-eight participants report that they have mixed and/or applied pesticides in the past, and 17 participants have mixed or applied pesticides in the past month. The majority of participants handling pesticides are male and work in agriculture, although non-AG participants and females also report handling pesticides. The frequency of using protective clothing for the 16 male participants who report handling pesticides in the past month are presented in Table 3.

The majority of participants completed all of the neurobehavioral tests (Table 4), however, adult female participants working in agriculture had lower completion rates (75% of the neurobehavioral tests) compared to other groups ($t_{173} = 4.48$, $p < 0.001$) that had an average of 88% completion rate. A large percentage of all participants were unable to complete the Reversal Learning test (approximately 68%). This was the last test presented in the lengthy battery and often participants did not have enough time to complete the test. The data from this test were excluded from the subsequent analyses.

The impact of age, years of education, gender and years working in agriculture was examined on each neurobehavioral measure. Table 5 presents the estimated slope ($\beta$-coefficient) showing the average change in each neurobehavioral measure per 5-year increase in the indicated predictor (age, years of education, years working in agriculture).

### 3.1. Age and neurobehavioral performance

Age was a major predictor of performance on Finger Tapping (preferred and non-preferred trials), Symbol-Digit, and Serial Digit Learning tests. As the age of the participants increased the performance on the neurobehavioral test decreased (Table 5). For example, performance on Finger

Table 2
Demographic characteristics of participants completing the neurobehavioral test battery

| | Adult AG, $n = 69$ | Adolescent AG, $n = 50$ | Adult non-AG, $n = 29$ | Adolescent non-AG, $n = 27$ |
|---|---|---|---|---|
| Age (mean and S.D.) | 28.2 (7.6) | 15.7 (1.6) | 30.7 (8.4) | 14.7 (1.8) |
| Percent female (%) | 33.3 | 30.0 | 51.7 | 51.9 |
| Education (years) (mean and S.D.) in | | | | |
| Country of origin | 4.7 (3.3) | 5.1 (3.3) | 7.5 (4.2) | 4.3 (3.7) |
| US | 0.3 (1.6) | 2.4 (3.8) | 1.2 (3.6) | 7.2 (3.4) |
| Any education in US (%) | 4 | 30 | 14 | 85 |
| Years working agriculture (mean and S.D.) | 9.0 (6.6) | 3.0 (3.3) | 2.7 (3.9) | 0.7 (1.8) |
| Ever worked in agriculture (%) | 100 | 100 | 72 | 37 |
| Males | | | | |
| Mix/apply pesticides (number and %) | 22 (48%) | 4 (11%) | 6 (43%) | 2 (15%) |
| Years in agriculture (mean) | 9.4 | 8.0 | 3.0 | 5.5 |
| Mix/apply past month (number) | 12 | 2 | 2 | 0 |
| Females | | | | |
| Mix/apply pesticides (number and %) | 2 (9%) | 1 (7%) | 0 | 1 (7%) |
| Years in agriculture (mean) | 6.5 | 1 | – | 1 |
| Mix/apply past month (number) | 0 | 0 | 0 | 1 |

Tapping (preferred hand) decreases an average of 2.4 taps for each 5-year increase in age. In addition, an interaction between age and gender was found for the Selective Attention Test (number of trials, latency). The older the female participants, the more performance on the Selective Attention measures decreased. The only measure that had improved performance for the adults was the d-prime measure of the Continuous Performance test (a measure of attentiveness, how well a participant distinguishes between targets and non-targets). In general, older subjects (35) tended to have slightly higher scores than did younger subjects with similar years spent working in agriculture. For those older subjects, scores appeared to increase with increasing years spent working in agriculture; for younger subjects, average scores tended to decrease.

### 3.2. Education and neurobehavioral performance

Years of education in the participant's country of origin was found to have a significant main effect on Digit Span (forward and reverse), Finger Tapping (alternating trials), Symbol-Digit, Reaction Time, Selective Attention (latency), Serial Digit Learning, Match-to-Sample (score), and Continuous Performance (Table 5). In each case as years of education increased performance on these measures improved.

Table 3
Frequency of use of protective clothing or equipment for male participants who reported mixing or applying pesticides in the past month ($n = 16$)

| | Always | Sometimes | Never |
|---|---|---|---|
| Rubber boots | 4 | 8 | 4 |
| Goggles or glasses | 3 | 4 | 9 |
| Rubber gloves | 6 | 8 | 2 |
| Plastic clothing | 3 | 6 | 7 |
| Mask | 2 | 6 | 8 |
| Respirator | 2 | 2 | 12 |
| Other protective clothing[a] | 3 | 3 | 10 |

[a] Handkerchief or support belt.

### 3.3. Gender and neurobehavioral performance

A significant main effect of gender was found on the Finger Tapping (preferred, non-preferred, and alternating trials) and Progressive Ratio Tests with females performing worse than males on these two tests (Table 5).

### 3.4. Years of agricultural work and neurobehavioral performance

A significant main effect of years working in agriculture was found for Match-to-Sample (score), as years spent working in agriculture increased performance decreased. An interaction between age and years working in agriculture was found for Continuous Performance (d-prime), older participants tended to have slightly better scores than younger participants with similar years spent working in agriculture.

Gender was also found to interact significantly with years working in agriculture on the Symbol-Digit, Reaction Time, and (for male participants) Selective Attention tests. For females, as years working in agriculture increased, performance on the Symbol-Digit and Reaction Time measures

Table 4
Percentage of tests completed by participants

| | Adult AG | Adult non-AG | Teen AG | Teen non-AG |
|---|---|---|---|---|
| Males (%) | 85 | 94 | 89 | 91 |
| Females (%) | 75* | 87 | 86 | 89 |

* Adult female participants working in agriculture had significantly lower completion rates than the other groups.

Table 5
Estimated slope ($\beta$-coefficient) showing the average increase or decrease in each neurobehavioral measure per 5-year increase in the indicated predictor (years working in agriculture, years of education, age)

| Neurobehavioral measure | Years in agriculture | Years of education | Age | Notes |
|---|---|---|---|---|
| Digit Span | | | | |
| Forward | | 0.49 (<0.01) | | |
| Reverse | | 0.34 (0.01) | | |
| Finger Tapping | | | | |
| Preferred | | | −2.4 (0.99) | Gender[a] |
| Non-preferred | | | −1.4 (0.97) | Gender[b] |
| Alternating | | 4.70 (0.01) | | Gender[c] |
| Symbol-Digit | | | | |
| Latency | M: −10 (0.57)<br>F: 480 (<0.01) | −300 (<0.01) | 155 (0.99) | |
| Match-Sample | | | | |
| Score | −0.61 (0.03) | 0.75 (0.05) | | |
| Reaction Time | | | | |
| Latency | M: −12 (0.94)<br>F: 32 (<0.01) | −21 (0.02) | | |
| Selective Attention | | | | |
| Trials | | | F: −12 (−0.96) | AG × age[d] |
| Latency | | −16 (0.02) | M: −5.9 (0.12)<br>F: 19 (0.99) | |
| Serial Digit Learn | | | | |
| Score | | 2.6 (<0.01) | −0.7 (0.98) | |
| Continuous Performance | | | | |
| %Hits | | 3.8 (0.02) | | |
| %False alarms | | −6.5 (<0.01) | | |
| %Omissions | | −3.7 (0.02) | | |
| d-Prime | | 0.6 (<0.01) | | AG × age[e] |
| Progressive Ratio | | | | |
| Number of taps | | | | Gender[f] |

Negative values for latency measures (Symbol-Digit, Reaction Time, Selective Attention) indicate improved performance. Measures that showed an interaction with gender are described separately for males (M) and females (F). One sided $p$-values are given in parentheses.

[a] Significant overall effect due to sex ($p < 0.01$); females averaged 17.4 fewer taps than males.

[b] Significant overall effect due to sex ($p < 0.01$); females averaged 11.7 fewer taps than males.

[c] Significant overall effect due to sex ($p < 0.01$); females averaged 13.2 fewer taps than males.

[d] Males showed an interaction between age and years in agriculture ($p = 0.01$); performance worsened for males as both age and years in agriculture increase together.

[e] Significant interaction between age and years in agriculture ($p = 0.04$); for older participants (≥35), scores increased as both age and years in agriculture increase together.

[f] Significant overall effect due to sex ($p < 0.01$); females averaged 87 points lower than males.

decreased; this effect was not significant for males. For males there was no effect on Symbol-Digit or Reaction Time. However, there was a compound effect of age and years working in agriculture for the males (linear × linear interaction). As both age and years of working in agriculture increased in males, performance on the Selective Attention measures decreased. For females, as age increased, performance on the Selective Attention measures decreased.

### 3.5. Pesticide handling and neurobehavioral performance

Neurobehavioral performance was examined in men ($n = 108$) to determine whether differences existed among three groups: those without any experience mixing/applying pesticides (68%; $n = 74$), those with any prior experience of mixing/applying pesticides (31%; $n = 34$) and a subset of the previous group of men who had mixed/applied pesticides in the month prior to testing (15%; $n = 16$). Multiple linear regression was used to control for differences due to age, years of education, and years spent working in agriculture. The expectation was for mixing/applying pesticides to lower neurobehavioral performance; consequently, one-sided $p$-values were used in comparing groups with some prior experience mixing/applying pesticides against the baseline group of non-mixer/applicators. Reported effects and/or changes reflect those for a 21-year-old man with 4 years of agricultural work experience and 5 years of education in his country of origin.

Any experience of mixing/applying pesticides was found to significantly decrease performance on four neurobehavioral measures. Scores on Digit Span forward and Digit Span reverse were significantly lower for men who had handled pesticides

(0.51 points lower for forward, $p = 0.02$ and 0.52 points lower for reverse, $p = 0.02$). Match-to-Sample scores were also lower (2.04 points) for men who reported handling pesticides in the past compared to men who had never reported handling pesticides ($p = 0.02$). The percentage of hits on the Continuous Performance test also showed a decrease for men who handled pesticides (6.4 percentage points, $p = 0.047$). Although not significant, performance was also decreased on Serial Digit Learning (2.02 points lower among men who had handled pesticides; $p = 0.09$) and Symbol-Digit (average latency 135 ms greater, $p = 0.21$). The Progressive Ratio test showed improved performance for men who had handled pesticides in the past (41.7 points higher).

When the subset of participants who had recent experience mixing/applying pesticides was compared to the participants who had no experience handling pesticides, three neurobehavioral measures showed decreased performance. Men who reported mixing/applying pesticides in the past month had an average Match-to-Sample score 2.68 points lower than participants with no experience handling pesticides ($p = 0.015$). The percentage of hits and d-prime score for the Continuous Performance test also showed decreased performance, 15.8 percentage points on percent hits and 0.79 points lower on d-prime score, for men mixing/applying pesticides in the past month compared to men with no pesticide handling ($p = 0.001$ and $p = 0.012$, respectively). The Progressive Ratio test showed that men who had recent experience mixing/applying pesticides had improved performance (25.8 more taps) compared to men with no experience handling pesticides (one-sided $p$-value = 0.85).

## 4. Discussion

The present study presents an analysis of results on neurobehavioral tests among a population of adolescent and adult farmworkers and comparison groups. Age, school experience, gender, and years working in agriculture all impacted performance on the neurobehavioral tests. Pesticide handling was also associated with performance on the neurobehavioral tests.

Age had an impact on the Finger Tapping, Symbol-Digit, Selective Attention and the Continuous Performance (d-prime) tests. With the exception of Continuous Performance, older participants performed worse than younger participants. Years of education had a significant impact on performance on eight out of nine neurobehavioral tests. As years of education increased, performance on the neurobehavioral tests improved.

Gender also had an impact on performance. On the motor tests, Finger Tapping and Progressive Ratio, females performed worse than males. This is consistent with Anger et al. (1997) who also found an effect of gender on a tapping measure in the same direction.

These findings suggest that years working in agriculture also impacted performance. More years working in agriculture was associated with worse performance on the Match-to-Sample, Symbol-Digit, Reaction Time, and Selective Attention tests. There also appears to be an interaction between years working in agriculture, age and gender on a number of measures. Similar gender effects were reported in an earlier study conducted in 1999 (Rothlein et al., 2006). While gender differences have been noted on specific neurobehavioral tests, these results and earlier findings suggest that there may be a differential impact from agricultural work as well. Other studies have also found lower performance on neurobehavioral tests associated with increased years working in agriculture (Kamel et al., 2003; Roldán-Tapia et al., 2005). Participants chronically exposed to pesticides for more than 10 years had lower performance on measures of perception and visuospatial processing (Roldán-Tapia et al., 2005). This study also showed no correlation between plasma cholinesterase, a measure of recent exposure, and cognitive deficits. Kamel et al. (2003) also found that the greatest decrease in cognitive and psychomotor functions was observed after 10 or more years of work.

Handling pesticides also impacted neurobehavioral performance. Thirty-four participants report mixing and applying pesticides. More males than females (34 versus 4) and more adults than adolescents (30 versus 8) reported handling pesticides. The years working in agriculture were very similar for the adult male participants who never handled pesticides (10.6 years and 2.1 years for the AG and non-AG groups) compared to the adult male participants who report mixing/applying pesticides (9.4 years and 3.0 years for the AG and non-AG groups). However, the male adolescent participants who never handled pesticides had fewer years working in agriculture (2.8 years and 1.5 years for the AG and non-AG groups) compared to the male adolescents who report mixing/applying pesticides (8.0 years and 5.5 years for the AG and non-AG groups). Personal protective equipment use was reported to be infrequent or not at all in the male participants who handled pesticides in the past month. Performance deficits associated with pesticide handling were found on the Digit Span, Match-to-Sample, and Continuous Performance Tests.

Interactions found between neurobehavioral performance and demographic variables such as age, education, and gender have been known to impact performance on neurobehavioral tests (Anger et al., 1997). Several neurobehavioral measures were significantly affected by the gender of the participant. Previous studies of neurobehavioral performance in farmworkers have generally assumed that observed deficits are a result of pesticide exposure (Kamel et al., 2003) and significant gender effects in humans have not been reported. Rothlein et al. (2006) reported gender differences on Finger Tapping, Serial Digit Learning and an overall summary index of neurobehavioral performance in Oregon farmworkers. Furthermore, several findings examining organophosphate exposure in rats have demonstrated differential effects of gender (Dam et al., 2000; Levin et al., 2001, 2002). Further research is warranted to examine the impact of gender.

These findings do not provide evidence that adolescents working in agriculture are more likely to perform more poorly on these tests than their adult counterparts. However, the results are limited in that no exposure variables are available other than years of working in agriculture and self-reported pesticides use. The results of four tests (Match-to-Sample, Selective Attention, Symbol-Digit, and Reaction Time) add to the increasing evidence that neurological impairment may be associated with increased years working in agriculture. Furthermore, the deficits found in the participants who reported handling pesticides compared to those with no experience indicate the potential impact of pesticide exposure. Time and exposure levels need to be examined to determine the dose–effect relationship. Longitudinal studies are needed to document if earlier onset of agricultural work results in increased deficits as a cohort ages.

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## References


Adams J, Barone SJ, LaMantia A, Philen R, Rice DC, Spear L, et al. Workshop to identify critical windows of exposure for children's health: neurobehavioral work group summary. Environ Health Perspect 2000;108:535–44.

Amler RW, Gibertini M, editors. Pediatric environmental neurobehavioral test battery. Atlanta: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; 1996.

Andersen SL. Trajectories of brain development: point of vulnerability or window of opportunity. Neurosci Biobehav Rev 2003;27:3–18.

Anger WK, Rohlman DS, Sizemore OJ, Kovera CA, Gibertini M, Ger J. Human behavioral assessment in neurotoxicology: producing appropriate test performance with written and shaping instructions. Neurotoxicol Teratol 1996;18:371–9.

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

Arcury TA, Quandt SA. Chronic agricultural chemical exposure among migrant and seasonal farmworkers. Soc Nat Resour 1998a;11:829–43.

Arcury TA, Quandt SA. Occupational and environmental health risks in farm labor. Hum Organ 1998b;57:331–3.

Bazylewicz-Walczak B, Majczakowa W, Szymczak M. Behavioral effects of occupational exposure to organophosphorous pesticides in female greenhouse planting workers. Neurotoxicology 1999;20:819–26.

Brown SA, Tapert SF, Granholm E, Delis DC. Neurocognitvie functioning of adolescents: effects of protracted alcohol use. Alcohol Clin Exp Res 2000;24:164–71.

Dam K, Seidler FJ, Slotkin TA. Chlorpyrifos exposure during a critical neonatal period elicits gender-selective deficits in the development of coordination skills and locomotor activity. Dev Brain Res 2000;121:179–87.

Farahat TM, Abdelrasoul GM, Amr MM, Shebl MM, Farahat FM, Anger WK. Neurobehavioral effects among workers occupationally exposed to organophosphorous pesticides. Occup Environ Med 2003;60:279–86.

Gabbard S, Carroll D, Baron S, Steege A. Teens in crop agriculture. In: National adolescent farmworker occupational health and safety advisory committee. Washington, DC: U.S. Department of Labor; 1999.

Grandjean P, Harari R, Barr DB, Debes F. Pesticide exposure and stunting as independent predictors of neurobehavioral deficits in Ecuadorian school children. Pediatrics 2006;117:e546–56.

Guillette EA, Meza MM, Aguilar MG, Soto AD, Garcia IE. An anthropological approach to the evaluation of preschool children exposed to pesticides in Mexico. Environ Health Perspect 1998;106:347–53.

Kamel F, Rowland AS, Park LP, Anger WK, Baird DD, Gladen BC, et al. Neurobehavioral performance and work experience in Florida farmworkers. Environ Health Perspect 2003;111:1765–72.

Levin ED, Addy N, Nakajia A, Christopher NC, Seidler FJ, Slotkin TA. Persistent behavioral consequences of neonatal chlorpyrifos exposure in rats. Dev Brain Res 2001;130:83–9.

Levin ED, Addy N, Baruah A, Elias A, Christopher NC, Seidler FJ, et al. Prenatal chlorpyrifos exposure in rats causes persistent behavioral alterations. Neurotoxicol Teratol 2002;24:733–41.

Loewenherz C, Fenske RA, Simcox NJ, Bellamy G, Kalman D. Biological monitoring of organophosphorus pesticide exposure among children of agricultural workers in central Washington state. Environ Health Perspect 1997;105:1344–53.

McCauley LA, Sticker D, Bryan C, Lasarev MR, Scherer JA. Pesticide knowledge and risk perception among adolescent Latino farmworkers. J Agric Safety Health 2002;8:397–409.

McCauley LA, Shapiro S, Scherer J, Lasarev M. Assessing pesticide safety knowledge among Hispanic migrant farmworkers. J Agric Safety Health 2004;10:177–86.

Meister JS. The health of migrant farm workers. Occup Med 1991;6:503–18.

Mines R, Gabbard S, Stierman A. A profile of U.S. farm workers. Demographics, household composition, income and use of services. Based on data from the national agricultural workers survey (NAWS). Washington, DC: The Commission on Immigration Reform; 1997.

Oliveira VJ, Effland JR, Hamm S. Hired farm labor use on fruit, vegetable, and horticultural speciality farms. Washington, DC: U.S. Department of Agriculture; 1993.

Reidy TJ, Bowler RM, Rauch SS, Pedroza GI. Pesticide exposure and neuropsychological impairment in migrant farm workers. Arch Clin Neuropsychol 1992;7:85–95.

Rohlman DS, Sizemore OJ, Anger WK, Kovera CA. Computerized neurobehavioral testing: techniques for improving test instructions. Neurotoxicol Teratol 1996;18:407–12.

Rohlman DS, Gimenes LS, Ebbert CA, Anger WK, Bailey SR, McCauley L. Smiling faces and other rewards: using the behavioral assessment and research system (BARS) with unique populations. Neurotoxicology 2000;21:973–8.

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

Rohlman DS, Anger WK, Tamulinas A, Phillips J, Bailey SR, McCauley L. Development of a neurobehavioral battery for children exposed to neurotoxic chemicals. Neurotoxicology 2001b;22:657–65.

Rohlman DS, Gimenes LS, Eckerman DA, Kang SK, Farahat FM, Kent AW. Development of the Behavioral Assessment and Research System (BARS) to detect and characterize neurotoxicity in humans. Neurotoxicology 2003;25:523–32.

Rohlman DS, Arcury TA, Quandt SA, Lasarev M, Rothlein J, Travers R, et al. Neurobehavioral performance in preschool children from agricultural and non-agricultural communities in Oregon and North Carolina. Neurotoxicology 2005;26:589–98.

Roldán-Tapia L, Parrón T, Sánchez-Santed F. Neuropsychological effects of long-term exposure to organophosphate pesticides. Neurotoxicol Teratol 2005;27:259–66.

Rosenstock L. Chronic central nervous system effects of acute organophosphate pesticide intoxication. Lancet 1991;338:223–7.

Rothlein J, Rohlman DS, Lasarev M, Phillips J, Muniz J, McCauley L. Organophosphate pesticide exposure and neurobehavioral performance in agriculture and nonagricultural Hispanic workers. Environ Health Perspect 2006;114:691–6.

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

Spear LP. Alcohol's effect on adolescents. Alcohol Res Health 2002;26:287–91.

Steenland K, Jenkins B, Ames RG, O'Malley M, Chrislip D, Russo J. Chronic neurological sequelae to organophosphate pesticide poisoning. Am J Publ Health 1994;84:731–6.

Stephens R, Spurgeon A, Calvert IA, Beach J, Levy LS, Berry H, et al. Neuropsychological effects of long-term exposure to organophosphates in sheep dip. Lancet 1995;345:1135–9.

Woodruff TJ, Kyle AD, Bois FY. Evaluating health risks from occupational exposure to pesticides and the regulatory response. Environ Health Perspect 1994;102:1088–96.