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Acute kidney injury and workload in a sample of California agricultural workers

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Abstract

Background: Kidney damage is associated with an increased workload in high ambient temperatures and may represent a pathway to chronic kidney disease of unknown origin in agricultural workers. We tested the associations of workload and heat with acute kidney dysfunction in California agricultural workers.

Methods: We recruited a convenience sample of 471 agricultural workers from 29 farms in California during two summer harvest seasons. The sustained 3-minute maximum workload was estimated using accelerometer data collected from Actical monitors and individual heat load through elevations in core body temperature. Acute kidney injury (AKI) was defined by a change in serum creatinine of ≥0.3 mg/dL or ≥1.5 times the preshift creatinine over the course of the work shift. Associations between AKI and workload were modeled using logistic regression, controlling for demographic, physiologic, and occupational variables.

Results: Of the total, 357 workers (75.8%) had accelerometer readings in the moderate workload category, 93 (19.7%) had readings in the vigorous category. 177 (36%) had elevations of core body temperature ≥1°C; 72 workers (14.9%) demonstrated evidence of AKI after a single day of agricultural work. The workload category was associated with an increased adjusted odds of AKI (1.92; 95% confidence interval, 1.05-3.51). Piece-rate work was also associated with increased adjusted odds of AKI (3.02; 95% CI, 1.44-6.34).

Conclusions: Heavy occupational workload and piece-rate work were associated with acute effects on the renal health of agricultural workers. This indicates that occupations requiring high physical effort put workers at risk for AKI, possibly independent of ambient and core body temperature. Changes to agricultural practices may reduce the risk of renal disorders for these workers.

KEYWORDS
acute kidney injury, agricultural workers, chronic kidney disease of unknown origin, metabolic equivalents, occupational risk factors, temperature

1 | INTRODUCTION

California employed over 829 000 farm workers in 2014, many of them undocumented immigrants from Mexico.[1] The nature of the work, with its physical demands and exposure to extreme weather during harvest season, increases the potential for adverse health outcomes in this population.[2-4] Recent evidence indicates an increased risk for acute kidney injury (AKI) across a work shift.[5]

AKI, defined as a subclinical injury to the kidneys usually resulting from reduced renal blood flow, appears in as little as 8 to 12 hours and resolves in approximately 24 to 48 hours.[6] It is possible that repeated episodes of AKI may lead to chronic kidney disease.[7] Among agricultural workers, this is particularly concerning because of reports of chronic kidney disease of unknown origin (CKDu) principally affecting young male agricultural workers who do not have the traditional risk factors of diabetes, hypertension, or obesity.[8,9] Studies of marathon runners and military recruits have documented cases of AKI resulting from periods of increased physical labor, especially when combined with heat exposure and volume depletion.[10-12] These findings are echoed in studies of CKDu where a connection between kidney damage and heavy workload in high ambient temperatures is established.[13,14] In wildland firefighters after prolonged physical exertion in extreme temperatures, elevations in creatine kinase, a marker of rhabdomyolysis has been noted.[15] This muscle damage leads to elevations in renal injury biomarkers, indicating AKI.[16] It is conceivable that similar damage induces AKI in agricultural workers. In previous work, we found an increased risk of AKI among workers who were paid by the piece, that is, by the amount they harvest.[17] Workers who are paid by the piece tend to work harder and faster than those paid by the hour because they can make more money,[18,19] suggesting that they experience higher workload and thus, a higher risk of AKI. We build upon our previous work and hypothesize that increased workload may result in a higher risk of AKI, a relationship that has not yet been examined in agricultural workers. Our purpose was to test associations of workload on AKI in a cohort of agricultural workers over the course of two harvest seasons.

2 | METHODS

Participants were recruited as part of the California Heat Illness Prevention Study, and methods have been described elsewhere.[17,20] Briefly, eligible participants for this study were adults age 18 or older, working in the fields for at least 6 hours per day, understood Spanish or English, and had no impediments to swallowing an ingestible sensor. All eligible participants were enrolled in the study for a single day of data collection and were given a small monetary incentive for their time. Participants were consented in their language of choice (English or Spanish) and signed written consent forms. We collected data at two-time points. At preshift data collection, we weighed participants in a base layer of clothing, took a capillary blood sample, fitted participants with a heart rate monitor, and asked them to swallow a temperature probe. Actical accelerometers, calibrated at the manufacturer, were firmly attached to the waist belt at the iliac crest of the hip using both a Velcro band through the mounting tabs and zip ties to ensure it remained in place during rough fieldwork. The Actical measures activity in all directions and provides readings in counts per minute (cpm), which can be converted to METS.[21,22] Accelerometers have been used in many studies for their convenience, negligible weight and size, and reliability. They are an objective way to measure physical activity.[23] At postshift data collection, approximately 7 to 10 hours after the preshift collection, we reweighed participants and collected another capillary blood sample. We took seated blood pressure, measured height without shoes, and orally administered a health questionnaire in Spanish.

2.1 | Outcome variable: AKI

We analyzed the capillary blood sample using the i-STAT point-of-care test to measure serum creatinine (Abbott Point of Care, Princeton, NJ). The i-STAT measurements are traceable to isotope dilution mass spectrometry through the standard reference material SRM967.[24] Baseline kidney function was estimated from the morning creatinine reading and categorized based on the Chronic Kidney Disease Epidemiology Collaboration equation[25]: ≥90, ≥60 to <90, or <60 mL/min/1.73 m^2. We compared preshift and postshift creatinine levels and classified AKI based on the recommended definition and stages of injury from the *Kidney Disease: Improving Global Outcomes* (KDIGO) group.[26] AKI was defined as an increase of serum creatinine by ≥0.3 mg/dL or ≥1.5 times the preshift creatinine. Staging was based on the following: stage 1 (≥0.3 mg/dL or 1.5-1.9 times preshift measure); stage 2 (2.0-2.9 times preshift measure); and stage 3 (≥3.0 times preshift measure).

2.2 | Predictor variable: workload

Using the cpm from the Actical readings, we computed summary statistics and tallied the number of minutes at the maximum, mean, and median cpm. We used the values for the sustained 3-minute cpm for these statistics. Due to a lack of variability in the data for the mean cpm, we categorized the sustained 3-minute maximum readings based on previously published cut-off points: sedentary (<100 cpm), light activity (100 to <1535 cpm), moderate activity (1535 to <3962 cpm), and vigorous activity (≥3962 cpm).[21]

2.3 | Covariates

We selected variables thought to be associated with AKI in occupational settings a priori based on current evidence and feasibility of collecting data in the field. Demographic variables included sex (male vs female); age (continuous); country of origin (US, Mexico vs Central America); and primary language (English, Spanish vs Indigenous). Occupational variables included years in farm work (≤5, 6-10, 11-20, >20 years); method of payment (hourly/salary vs piece-rate); income (≤$10 000, $10 001-30 000, >$30 000); how the participant was hired (by the farmer directly vs a labor contractor); and primary farm task during the day (picking/harvesting, hoeing/raking/shoveling/grounds-keeping, irrigation, packing/sorting, pruning, multitasking, or other [eg, supervising, repair, or fumigating]).[27]

Heat exposure during the workday was estimated using the 3-minute maximum ambient heat each day measured via a wet

bulb globe thermometer (WBGT) placed in a central location at each of the sampling farms. We used a change in core body temperature over the course of the day to estimate a participant's individual heat strain. We calculated the sustained 3-minute maximum core temperature reading during the day,[20] and calculated a change in body temperature by subtracting the 3-minute maximum from the baseline reading. All participants had at least some increase in core body temperature over the course of the day, so we categorized the change as either ≥1°C vs <1°C. Volume depletion was calculated by comparing the weight taken at postshift to the preshift weight and classified as no body mass change, gained body mass, lost <1.5% body mass, or lost ≥1.5% body mass. The National Institute of Occupational Safety and Health (NIOSH), classifies workers as dehydrated if they lose more than 1.5% of their body mass during the day.[28] Body mass index (BMI) was calculated from preshift weight and height measurements and classified according to World Health Organization recommendations[29]: normal weight (BMI <25 kg/m^2), overweight (BMI 25.0-29.9 kg/m^2), or obese (BMI >30 kg/m^2). Diabetes status was estimated by HgA1c, via the capillary blood sample taken in the morning and self-report of diabetes or antidiabetic medicine[30]: no diabetes (HbA1c <5.7% and no self-reported antidiabetic medications), prediabetes (HbA1c 5.7%-6.4%), or diabetes (HbA1c ≥6.5% or self-reported diabetes diagnosis or antidiabetic medications). We categorized blood pressure based on Joint Commission recommendations[31]: normal (<120/80 and no self-reported antihypertensive medications), prehypertension (120-139/80-89) or hypertension (≥140/90 or self-reported hypertension diagnosis or antihypertension medications). We also asked about personal or family history of kidney disease (none, personal vs family). Finally, we included two-time variables in our analyses: one to account for the week of data collection to estimate if AKI occurred more frequently in workers who were sampled later in the summer or who had worked for a longer amount of time over the summer; and a second variable of year of data collection (year 1 vs year 2) to estimate differences by year that were not assessed by measured variables (eg, shade availability, length of breaks, work team compositions, etc). Because we included participants who were part of our first analysis of AKI,[17] we included the year variable to determine if there were differences between the workers in the 2 years.

2.4 | Statistical analysis

Participant characteristics were stratified as outlined above and frequencies and percentages calculated. χ^2 tests[32] were used to compare variables frequencies between sexes. Fisher's exact test[33] was used to examine frequency differences in heat strain, volume depletion, and workload across the KDIGO stage due to small sample sizes within some cells. Logistic regression[34] was used to model the associations of AKI and workload as a continuous variable. We used a forward stepwise regression[35] model selection technique with the Akaike value as a criterion for the best fitting model.[36] Analyses were

then adjusted for age and sex (model 2); followed by heat exposure variables including volume depletion (lost <1.5% body mass [reference] compared with lost ≥1.5% body mass), change in core body temperature (continuous), and 3-minute maximum WBGT (continuous) (model 3). We added occupational variables to the next model and adjusted for the number of years in agriculture (continuous), farm task (picking compared to other [reference]), week of the harvest (continuous), and year (2014 [reference] compared with 2015). Finally, in model 5 physiologic variables, including BMI (BMI <25 [reference], BMI 25-30 compared with BMI >30), diabetes status (A1c <5.7% [reference] compared with A1c ≥5.7%), blood pressure (<120/80 [reference] compared with ≥120/80), history of kidney disease (none [reference] compared with personal or family history), and the eGFR (continuous) were added.

To examine the effect piece-rate work may have on the relationship of the workload with AKI, we tested the interaction of payment type with the workload. However, due to model quasi-separation issues, we were unable to include the interaction term in our model. We did run models to test the interaction of sex and workload and sex and payment type. Those were not significant and did not change estimates appreciably.

All analyses were completed using SAS v 9.4 and Stata 12.

The study protocols and procedures were approved by the Institutional Review Board of the University of California, Davis, where the study was conducted.

3 | RESULTS

3.1 | Participant characteristics

We collected results from 492 participants, but we only had complete results on 471, who were included in this analysis. There were 298 male and 173 female participants. Demographic and health data are shown in Table 1. Our sample was mostly over age 25, and only 7.43% were born in the United States. The majority spoke Spanish as their primary language. The majority of participants reported working in farm work for more than 6 years, and men reported more years in farm work than women (P < .01). Most participants were paid by the hour or salaried, versus piece-rate, and the median yearly income was between $10 001 and $30 000, though men reported earning more money than women (P < .01). Men reported being hired by the farm directly more than women who tended to be hired by labor contractors (P < .01). Women reported their main tasks as pruning or packing and sorting, while men were more often involved in picking or harvesting (P < .01). Nearly half of the sample (44.4%) was overweight and over a third (35.5%) was obese, with women forming a higher proportion of each category than men (P = .02). Very few participants had diabetes (4.7%), and 16.1% had prediabetes. Most participants were either prehypertensive (48.0%) or hypertensive (23.4%); men were more likely to be prehypertensive while women were more likely to have normal blood pressure (P < .01). Most participants had normal eGFR, while 4.5% had eGFR between 60 and 89 mL/min/1.73 m^2,

TABLE 1 Characteristic of study participants

	Total sample (n = 471)		Male (n = 298)		Female (n = 173)		
	n	%	n	%	n	%	P value[a]
Age group							.19
18-25, y	72	15.29	52	17.44	20	11.56	
26-40, y	211	44.80	127	42.61	84	48.55	
41-54, y	126	26.75	76	25.50	50	28.90	
Over 55, y	62	13.16	43	14.43	19	10.98	
Country of origin							<.01
United States	35	7.43	31	10.40	4	2.31	
Mexico	420	89.17	259	86.91	161	93.06	
Central America	16	3.40	8	2.68	8	4.62	
Primary language							.40
English	25	5.31	19	6.37	6	3.47	
Spanish	427	90.66	267	89.59	160	92.49	
Indigenous	19	4.03	12	4.02	7	4.04	
Years in farmwork							<.01
5 or less	139	29.64	82	27.70	57	32.95	
6-10	86	18.34	45	15.20	41	23.70	
11-20	141	30.06	87	29.39	54	31.21	
More than 20	103	21.96	82	27.70	21	12.14	
Payment type							.20
Hourly/salary	366	77.71	226	75.84	140	80.92	
Piece-rate	105	22.29	72	24.16	33	19.07	
Income							.01
$10 000 or less	107	23.57	55	19.16	52	31.14	
$10 001-30 000	241	53.08	157	54.70	84	50.30	
$30 001 or more	106	23.35	75	26.13	31	18.56	
Hired by							<.01
Farm directly	220	46.71	161	54.03	59	34.10	
Labor contractor	251	53.29	137	45.97	114	65.90	
Farm task							<.01
Picking/harvesting	140	29.72	97	32.55	43	24.86	
Hoeing/raking/shoveling/grounds-keeping	37	7.86	21	7.05	16	9.25	
Irrigation	47	9.98	47	15.77	0	0.00	
Packing/sorting	68	14.44	20	6.71	48	27.75	
Pruning	94	19.96	34	11.41	60	34.68	
Multitask	61	12.95	58	19.46	3	1.73	
Other[b]	24	5.10	21	7.05	3	1.73	
BMI							.03
Normal weight (<25 kg/m^2)	95	20.17	71	23.83	24	13.87	
Overweight (25-30 kg/m^2)	209	44.37	127	42.62	82	47.40	
Obese (>30 kg/m^2)	167	35.46	100	33.56	67	38.73	
HgA1c							.20
HgA1c <5.7% (no diabetes)	368	79.14	239	81.57	129	75.00	
HgA1c 5.7-6.4% (prediabetes)	75	16.13	43	14.68	32	18.60	
HgA1c ≥6.5% (diabetes)	22	4.73	11	3.75	11	6.40	
Blood pressure[c]							<.01
Normal blood pressure (<120/80)	135	28.66	54	18.12	81	46.82	
Prehypertensive (120-139/80-89)	226	47.98	162	54.36	64	36.99	
Hypertension (≥140/90)	110	23.35	82	27.52	28	16.18	
eGFR at morning sample[d]							.21
≥90 mL/min/1.73 m^2	450	95.54	282	94.63	168	97.11	
60-89 mL/min/1.73 m^2	21	4.46	16	5.37	5	2.89	
<60 mL/min/1.73 m^2	0	0.00					

(Continues)

TABLE 1 (Continued)

	Total sample (n = 471)		Male (n = 298)		Female (n = 173)		
	n	%	n	%	n	%	P value[a]
History of kidney disease							.31
None	426	91.03	272	92.20	154	89.01	
Personal history	42	8.97	23	7.80	19	10.98	
Family history	92	19.80	54	18.40	38	22.20	
Year of data collection							.35
2014	240	50.96	147	49.32	93	53.75	
2015	231	49.04	151	50.67	80	46.24	

Abbreviations: BMI, body mass index; HgA1c, hemoglobin A1c, from capillary blood sample; KDIGO, Kidney Disease Improving Global Outcomes.
[a]Differences based on χ^2 tests between males and females.
[b]"Other" includes supervising staff, machinery repair, shoveling dirt, or fumigating.
[c]Blood pressure based on JNC7 categories.
[d]Categorized based on KDIGO guidelines.

and most (91.0%) reported no personal or family history of kidney disease. We included 240 participants from 2014 and 231 participants from 2015.

3.2 | AKI and occupational risks

Among 471 participants, 70 (14.9%) had cross-shift elevations in serum creatinine high enough to classify them as incurring AKI. A total of 59 participants (12.5%) had stage 1 AKI and 11 (2.3%) had stage 2. No participant was classified as stage 3 AKI. There were no statistically significant differences between males and females, so we conducted subsequent analyses on pooled data for both sexes. The average 3-minute maximum WBGT during data collection was 30.3°C/86.5°F (95% confidence interval [CI], 27.11°C-33.4°C/ 80.8°F-92.1°F). None of the participants had a 3-minute maximum workload in the sedentary category, and 21 (4.5%) had 3-minute maximum values in the light work category. The majority of the sample (357 participants, 75.8%) had 3-minute maximum workload measurements in the moderate category, and 93 participants (19.7%) had 3-minute maximum measurements in the vigorous category. There were no statistically significant differences in workload categories based on sex, change in core body temperature, payment method, or year of data collection. There were differences in volume depletion and AKI. Relatively, few people in the vigorous category had no body mass change (16.7%) or gained body mass (14.8%), which suggests that few of these hardest-working participants were adequately hydrated across their shift (P = .02). Sixty percent of those who lost more than 1.5% of their body mass during the shift was in the moderate category, and 38% were in the vigorous category (P = .02). For participants in the vigorous workload category, 17.2% had no AKI, 33.9% had stage 1 injury, and 36.4% had stage 2 injury (P = .03). Results are shown in Table 2.

When we looked at AKI as a binary variable (AKI ≥ stage 1 v. not), we found that of those with vigorous workload measurements, 25.8% had AKI contrasted with 12.3% of those with the moderate workload, and only 9.5% with light workload (P < .01). These results are illustrated in Figure 1, which shows the dose-response relationship of workload to AKI and demonstrates that as the workload increased, participants with cross-shift AKI increased.

Results from the logistic regression models are shown in Table 3. In the unadjusted model, the 3-minute maximum workload was significantly associated with AKI with an odds ratio (OR) 2.28, (95% CI, 1.36-3.85). This association changed little with the addition of age and sex variables. Variables related to heat exposure (volume depletion, change in core body temperature, and maximum daily WGBT) similarly did not change the estimates for the workload (adjusted odds ratio [AOR], 2.21; 95% CI, 1.28-3.82). The addition of occupational variables (model 4) resulted in a small decline in the AOR for the workload to 2.17 (95% CI, 1.23-3.81) while piece-rate work was associated with an AOR for AKI of 2.75 (95% CI, 1.39-5.47). Year of data collection was also statistically significantly associated with higher odds of AKI: those sampled in 2015 had AOR 2.17 of AKI (95% CI, 1.21-3.91). In the final model, after adding physiologic characteristics that may increase the risk for AKI, workload remained statistically significantly associated with AKI, though the AOR reduced to 1.92 (95% CI, 1.05-3.51). Piece-rate work remained significant with increased adjusted odds of AKI (AOR, 3.02; 95% CI, 1.44-6.34). The association with the year of data collection was no longer statistically significant in this model. The maximum daily temperature, independent of workload, showed a small association with AKI in the final model (AOR, 1.09; 95% CI, 1.00-1.20). Using the Akaike criteria for model selection, model 5 (AIC 358.56) was the best fit for the data.

4 | DISCUSSION

In a sample of 471 agricultural workers, we found evidence for AKI across a work shift in 70 (14.9%) participants. Payment type (piece work) and workload were significantly associated with higher odds of AKI. Our estimates of AKI in 2 years of data collection are slightly higher than we previously estimated in a single year of data collection (12.4%).[5] The current work builds on our previous estimates by investigating the potential role of workload on the

TABLE 2 Maximum workload, occupational risk factors, and acute kidney injury (n = 471)

	Light (100-1534 cpm)		Moderate (1535-3691 cpm)		Vigorous (≥3692 cpm)			
	n	%	n	%	n	%	P value[a]	Row total
Total sample (n = 471)	21[b]	4.5	357	75.8	93	19.7		
Sex								
Male	11	3.7	220	73.8	67	22.5	.10	298
Female	10	5.8	137	79.2	26[c,d]	15.0		173
Volume depletion[e]								
No body mass change	2	11.1	13	72.2	3	16.7	.02	18
Gained any body mass	3	2.8	89	82.4	16	14.8		108
Lost <1.5% body mass	15	5.1	224	76.2	55	18.7		294
Lost ≥1.5% body mass	1	2.0	30	60.0	19	38.0		50
Change in core body temperature[f]								
<1°C	14	4.8	226	76.9	54	18.4	.59	294
≥1°C	7	4.0	131	74.0	39	22.0		177
Payment method								
Piece-rate	19	5.2	279	76.2	68	18.6	.23	366
Hourly/salary	2	1.9	78	74.3	25	23.8		105
Acute kidney injury								
No injury	19	4.7	313	78.1	69	17.2	.03	401
Stage 1	2	3.4	37	62.7	20	33.9		59
Stage 2	0	0.0	7	63.6	4	36.4		11
Year of data collection								
2014	10	4.2	191	79.6	39	16.3	.13	240
2015	11	4.8	166	71.9	54	23.4		231

Abbreviation: cpm, counts per minute.

[a]P value based on Fisher's exact tests.

[b]Workload categorized by sustained 3-min maximum counts per minute from accelerometer data.

[c]Estimated from serum creatinine measurements and classified per Kidney Disease Improving Global Outcomes.

[d]Stage 1 classified based on meeting at least one of the criteria.

[e]Volume depletion estimated by the percent change in body mass (postshift weight − preshift weight) × 100%/preshift weight.

[f]Estimated from an elevation from the baseline reading from the ingested sensor.

incidence of AKI during a work shift. We find that increased workload is associated with a nearly two-fold increase in the odds of developing AKI at work. Studies in Central America of agricultural workers with CKDu suggest that increased workload contributes to decreased renal function and potentially leads to chronic kidney disease.[37,38] Interventions designed to encourage workers to rest and hydrate throughout the workday target this assumption, and are successful in reducing the number of persons with kidney damage.[39] In California, occupational regulations seek to protect

FIGURE 1 Percent of workers with AKI in workload categories. AKI, acute kidney injury [Color figure can be viewed at wileyonlinelibrary.com]

workers by promoting rest breaks, regular hydration, and the provision of shade (Cal-OSHA Heat Illness Regulation 3395). It is unclear whether these regulations are sufficient to protect the health of the kidneys, but these findings suggest that the importance of rest cannot be overstated.

The link between high physical exertion and renal disorders is well-documented. For example, workers who are chronically dehydrated and who have high levels of exertion in high ambient temperatures have a higher risk of kidney stones.[40,41] Associations between high levels of physical activity and kidney function have been shown in studies of athletes who experience AKI after intense physical exertion.[10,42] When the body's workload increases, muscle injury may result, with the release of myoglobin, which lodges in kidney tubules. This process of rhabdomyolysis, which is usually benign, can be aggravated by external factors such as heat and dehydration.[43] In addition, if previous instances of muscle damage are combined with strenuous exercise, the risk of AKI increases, independent of hydration status.[44] While the majority of our sample had activity readings in the moderate workload category, the association between higher workload and AKI suggests that workers who work multiple days in a row may incur injuries that compound across a working
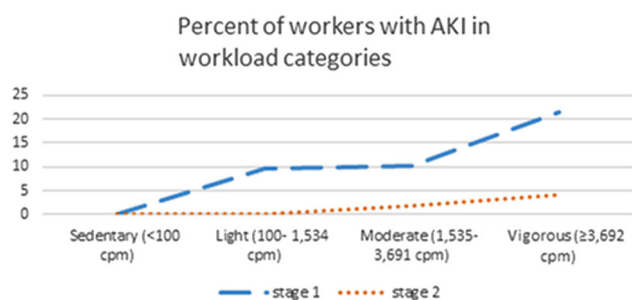
TABLE 3 Odds of acute kidney injury[a] based on logistic regression (n = 471)

	Model 1			Model 2			Model 3			Model 4			Model 5		
	OR	95% CI	P value	AOR	95% CI	P value	AOR	95% CI	P value	AOR	95% CI	P value	AOR	95% CI	P value
3-Min maximum workload[b]	2.28	1.36-3.85	<.01*	2.23	1.31-3.79	<.01*	2.21	1.28-3.82	.01*	2.17	1.23-3.81	.01*	1.92	1.05-3.51	.03*
Age in years				1.00	0.98-1.02	.77	1.00	0.97-1.02	.70	0.99	0.96-1.02	.56	1.05	1.01-1.09	.04*
Sex															
Male (reference)															
Female				0.89	0.51-1.53	.67	0.94	0.53-1.66	.83	1.11	0.61-2.05	.73	0.61	0.29-1.30	.20
Volume depletion[c]															
Lost <1.5% body mass (reference)															
Lost ≥1.5% body mass							0.65	0.27-1.57	.34	0.52	0.21-1.29	.16	0.55	0.21-1.40	.21
Change in core body temperature							1.76	0.83-3.74	.14	1.8	0.81-4.04	.15	2.00	0.85-4.72	.11
Max daily WBGT							1.01	0.93-1.10	.80	1.06	0.97-1.15	.81	1.09	1.00-1.20	.05
Piece-rate work[d]										2.75	1.39-5.47	<.01*	3.02	1.44-6.34	<.01*
Years in agricultural work										1.02	0.99-1.05	.23	1.02	0.99-1.06	.23
Farm task															
Picking										1.40	0.75-2.61	.30	1.57	0.81-3.04	.18
Other (reference)															
Week										1.02	0.95-1.09	.66	1.04	0.97-1.12	.30
Year										2.17	1.21-3.91	.01*	1.18	0.61-2.30	.62
BMI[e]															
Normal weight (BMI <25) (reference)															
Overweight (BMI 25-30)													0.69	0.32-1.51	.35
Obese (BMI >30)													1.20	0.54-2.68	.65
Diabetes[f]															
A1c <5.7% (reference)															
A1c ≥5.7%													0.66	0.31-1.42	.29
Blood pressure[g]															
Normal blood pressure (<120/80) (reference)															
Elevated blood pressure (≤120/80)													1.05	0.51-2.18	.90

(Continues)

TABLE 3 (Continued)

	Model 1			Model 2			Model 3			Model 4			Model 5		
	OR	95% CI	P value	AOR	95% CI	P value	AOR	95% CI	P value	AOR	95% CI	P value	AOR	95% CI	P value
History of kidney disease															
None (reference)															
Personal or family history													1.20	0.63-2.29	.58
Baseline eGFR													1.07	1.04-1.10	<.01*
AIC		390.47			394.20			394.53			378.42			355.07		

Abbreviations: AOR, adjusted odds ratio; BMI, body mass index; CI, confidence interval; HgbA1c, hemoglobin A1c.

[a]Acute kidney injury based on Kidney Disease Improving Global Outcomes classification of elevations in serum creatinine.

[b]Workload as continuous data from Actical counts per minute.

[c]Percent body mass loss based on comparing preshift weight in kilograms and postshift weight in kilograms.

[d]Payment by the piece compared to by the hour or salaried.

[e]BMI categorized based on World Health Organization recommendations.

[f]HgbA1c from a capillary blood sample.

[g]Blood pressure based on JNC7 categories.

*Significant at α = .05.

period. On the other hand, one study of AKI conducted in the lab during exercise in the heat showed that as participants were acclimated to exertion in the heat, subsequent elevations in serum creatinine were not as severe, due to the capacity of the kidneys for autoregulation.[45] The importance of acclimatization cannot be understated in agricultural workers and is part of the NIOSH recommendations to prevent heat-related illness in workers. We did not have enough variability in our data to assess acclimatization, but we attempted to estimate this using the week of the harvest as a variable. As this estimate proved nonsignificant in our analyses, we cannot make a clear statement about the acclimatization of our sample and the effect this has on the development of AKI.

Independent of the effect of workload on kidney function, we found that workers paid by the piece had higher odds of AKI. This finding is surprising, given the assumption that that piece-rate payment incentivizes the worker to work faster and harder to earn more money.[46] This is especially true when work is seasonal and irregular,[47] though we found no statistically significant differences in the workload categories between those who were paid by the piece and those who were paid hourly or on salary. Studies of workers who are paid by the piece continuously cite increased risks from this method of compensation, even though this is a popular method of payment because workers can make more money for less time working.[46] Our previous work found that workers paid by the piece were at increased risk of AKI when we examined piece-rate work independently.[17] This study builds upon that report with the finding that piece-rate work exerts its own effect on AKI, independent of workload; however, because we did not find a significant interaction between piece-rate work and workload, these two variables need to be considered independent risk factors for AKI. Piece-rate work may capture other working conditions, which we did not include in our data collection. It is possible that workers paid by the piece take shorter breaks than those paid by the hour. It is also conceivable that piece-rate workers have more peer pressure than hourly workers do, especially if they are paid piece-rate as a team. Piece-rate work increases the likelihood that a worker will experience heat-related illness and even death,[3,48] and while piece-rate work was not associated with heat strain in our work, nor was heat strain associated with AKI, other studies document the association of heat strain and AKI. A meta-analysis by Flouris et al[49] found that 15% of workers who experience heat stress also experience AKI or kidney disease. Workers paid by the piece tend to be unauthorized immigrants with lower levels of education and English-language skills.[46] We did not assess immigration status or education level, but other work points to external factors that may contribute to increased risk of AKI for piece-rate workers that we did not capture and are external to the payment mechanism alone.

We found that baseline kidney function, as estimated by the eGFR, was associated with slightly higher odds of developing AKI over the shift, as did age. We hypothesize that workers who experience the occupational risks of agricultural work that may cause

harm to the kidneys are largely unaware of their injury and can repeatedly damage their kidneys with each day of work. In common with other studies of CKDu which find that kidney disease is related to occupational or environmental exposures,[50] we found no association between kidney function and traditional risk factors of diabetes, hypertension, and overweight/obesity. While the demonstrable cause (s) of CKDu is as yet unknown, researchers hypothesize that CKDu could be a result of heat exposure and dehydration during the workday, like most agricultural workers affected by the disease work in extreme temperatures without adequate hydration.[51] However, our findings suggest that the workload and payment methods appear to be stronger risks than heat exposure nor hydration in their contribution to a decrease in kidney function.

The overwhelming majority of the workers we sampled had 3-minute maximum activity levels in the moderate stage, suggesting that the agricultural work that we measured in this study may have been less physically demanding than we might have originally surmised. There are few data on the workload of agricultural workers in the literature, although most assessments of physical demand levels (eg, O*NET, DOT) put farmworkers at the high end of workload. A pilot study of 10 hand planters working in reforestation revealed that workers spend most of their day in moderate and vigorous activity,[52] and another study of brush cutters reported that workers have high levels of physical activity as estimated by heart rates.[19] Finally, an analysis of cane cutters (the primary occupation of those affected by CKDu) found that workers spent more than half of the day at 50% of their maximum heart rate, indicating extremely physically demanding labor.[37] Workers in our sample did not log these high activity levels, perhaps because of the nature of the work which included hand-sorting or pruning.[27] It is difficult to compare our findings to those of cane cutters, therefore, because of the variations between the activities. In addition, no one in our sample had eGFR <60 mL/min/1.73 m^2, which further differentiates our sample from those in Central America.

Some limitations of this study should be noted. The first is the sampling method of recruiting participants at their sites of employment. This convenience sample may be biased if employers who allowed us to collect data on their farms were more likely to follow occupational regulations to protect workers. Therefore, our estimates may be low. An additional limitation is the lack of variability in the mean workload measurement. We suspected that AKI would be associated with a higher workload over the course of the day, as captured by a mean workload, but we were unable to estimate this in our analysis. Our estimate of the 3-minute moving maximum workload ensured that we did not measure only one single moment of intense workload. Knowing how the maximum workload affects AKI is important because it suggests potential mechanisms inherent in hard physical labor that may affect the kidneys. Due to the design of our study, we were unable to collect data, including measures of rhabdomyolysis, to further estimate these effects. In addition, despite the potential risks of pesticide exposure on the health of the kidneys, we did not collect information on pesticide exposure in our study and are unable to include this in our analysis.[53,54] A final limitation is the potential for error in our estimates of AKI based on a point-of-care test of serum creatinine. A recently published study reported that point-of-care testing may overestimate creatinine levels.[55] While this is a significant potential limitation in our data, other studies of AKI in agricultural workers find similar results using different assessment methods. The strengths of this study include the large sample size collected over two summer harvest seasons and the physiologic measurements of AKI, workload, and heat strain. In particular, we use an objective measure of workload via accelerometers in a sample whose work tasks are varied.[27]

Our study is the first to estimate the effect of workload on measures of AKI in a sample of agricultural workers in the United States. Given the establishment of these factors as risks to kidney function in other populations, these findings have implications for occupational standards in the agricultural sector. Continued attention to NIOSH recommendations that encourage workers to rest in the shade during the workday may have effects beyond those of preventing heat-related illness and may help protect the kidneys. Understanding potential modifications to existing work structures is important not only for the protection of workers in the United States but also to elucidate the potential etiology of CKDu, which affects workers globally.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John D. Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

AUTHOR CONTRIBUTIONS

SM is responsible for conceptualization, analysis decisions, and manuscript preparation. TA is responsible for data analysis. DM is responsible for data collection, analysis, and manuscript editing. MS is responsible for study design and manuscript editing. All authors are responsible for the content of the manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

ETHICS APPROVAL AND INFORMED CONSENT

The study protocols were approved by the Institutional Review Board at the University of California, Davis, where the study was

conducted. All participants were consented in their preferred language (English or Spanish) via a signed paper consent form.

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