Published in final edited form as:
*J Occup Environ Med*. 2024 September 01; 66(9): 694–705. doi:10.1097/JOM.0000000000003142.

# Longitudinal Renal Function Degradation Among Florida Agricultural Workers

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## Abstract

**Objective:** This longitudinal study evaluated renal function and acute kidney injury (AKI) over time in U.S. agricultural workers.

**Methods:** We followed Florida agricultural workers from January 2020 to August 2022, collecting blood and urine pre- and post-workday during 5 visits.

**Results:** Pre-workday eGFR function in all participants was lower in summers but relatively consistent over time. In participants who worked almost exclusively in fernery operations (piece-rate compensation), we observed a high incidence of post-workday AKI in 2020 (21%) that increased to 43% by the end of the study. In comparison, 11% of nursery workers (hourly compensation) had AKI, and this rate was fairly stable.

**Conclusion:** AKI risk over time differs according to the type of agricultural work. Piece rate workers who are incentivized to forgo rest breaks and hydration to earn higher wages demonstrate steadily increasing rates of AKI.

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Author Contributions:
The authors confirm contribution to the paper as follows:
Study conception and design: RCC, NX, VH, JMS, LM
Data collection: RCC, NX, LB
Analysis and interpretation of results: RCC, LE, NX, DL, MCH, VH, JMS, LM
Draft manuscript preparation: RCC, LE, MCH, TM, LB
All authors reviewed the results and approved the final version of the manuscript.

**Conflict of Interest for ALL Authors:** NONE DECLARED

**Ethical Considerations & Disclosure:** The Institutional Review Board at Emory University provided approval (IRB00112681) for the study, and all participants provided informed consent.

**Keywords**

agricultural workers; piece-rate; acute kidney injury; dehydration; heat

## INTRODUCTION

Renal dysfunction among agricultural workers has been an area of intense scientific debate and investigation, with the role of heat stress being a prominent area of inquiry.[1–6] Most studies to date have documented chronic kidney disease of unknown etiology (CKDu) (also referred to as Chronic Kidney Disease of non-traditional origin [CKDnt][7] and Mesoamerican nephropathy [MeN][8]) among workers in agricultural regions in Central America. The causes of CDKu remain elusive, but several global studies have documented the degradation of renal function longitudinally in agricultural workers,[9–16] suggesting that repeated episodes of AKI among agricultural workers may increase the risk of CKDu development.[7,17–20]

Cross-sectional studies that measured creatinine pre- and post-work shift have reported acute kidney injury (AKI) among agricultural workers both in the United States (U.S)[21,22] and internationally.[14,23,24] Agricultural worker studies of heat stress and renal dysfunction have determined AKI using the Kidney Disease: Improving Global Outcomes (KDIGO) criteria that defines AKI as either an increase in the creatinine level by ≥ 0.3 mg/dL or an increase in the creatinine level to ≥ 1.5 times the pre-shift level.[14,21–25]

While the prevalence of AKI has been reported in both agricultural workers in Central America and in the U.S., few studies have measured renal function longitudinally over the course of a harvest period or over multiple harvesting periods. Renal function for longer than a harvest season has been reported by including retrospective clinical data from pre-employment screenings before previous harvest seasons. Wesseling et al., (2016)[11] documented a decrease in eGFR after only 9 weeks of sugarcane harvesting, and Laws et al (2016)[10] indicated an association of decreases in renal function with biomarkers suggestive of tubular injury. Sorenson et.al, (2020) studied Guatemalan sugarcane workers over a 4-year period by retrospectively analyzing data from the pre-harvest medical employment screenings (years 2012–2016) for the study participants they prospectively monitored in 2017, and they described degradation in eGFR.[9]

There is a clear need for longitudinal tracking of renal function and interventions to interrupt this decline in renal function. The U.S. is also susceptible to rising global temperature, and AKI in agricultural workers has been reported in cross-sectional studies in Florida and California.[21,22] Furthermore, two studies have reported ‘hot spots’ of unexplained end-stage renal disease (ESRD) in agricultural areas in the U.S.[29,30] Thus, incidence of AKI and progressive degradation in renal function may be increasing among U.S. agricultural workers. To our knowledge, no published studies in the U.S. have examined renal function and injury of agricultural workers longitudinally. This paucity of research is often influenced by the inability to recruit and follow workers because of worker immigration status even though they may have worked in agriculture for years.[26–28]

This paper describes the results of a community-engaged research program conducted in partnership with the Farmworker Association of Florida (FWAF) which supports and advocates for this marginalized population that is at increased risk of climate-related health impacts. Through this partnership, we have been able to follow research participants engaged in different types of agricultural work over multiple harvesting seasons to characterize differences in renal function when working in both cool and hot environments and to study degradation of renal function and AKI incidence over time. In addition to the influence of heat exposure on renal dysfunction and decline among these workers, we examined risks falling under three categories: health factors, working conditions and habits, and hydration practices and indicators.

## METHODS

Trained community workers from the FWAF recruited a convenience sample of agricultural workers in two central Florida locations in January 2020 for a longitudinal study of heat exposure and renal function. Workers were eligible for the study if: (a) they were 18 to 49 years of age at the time of study, (b) self-identified as Hispanic/Latino, and (c) had worked in agricultural settings for at least 1 month prior to study participation. Exclusions included a history of Type 1 diabetes, pregnancy at the time of enrollment, under treatment for hypertension, or reported history of glomerulonephritis, pyelonephritis, renal calculi, or snake bite. This study was approved by the Institutional Review Board of Emory University (IRB00112681), and informed consent was obtained.

### Data Collection Procedures and Variables

At each visit, participants met with study personnel in the FWAF field offices for clinical and non-clinical data collection; all data were saved in the REDCap platform[29]. At the first visit, participants met on a non-workday to have their height, weight, and blood pressure recorded and a fingerstick to collect blood for analysis of hemoglobin A1C (A1CNOW®, pts Diagnostics, Whitestown, IN); weight, A1C, and blood pressure were measured again at each visit. Study personnel orally queried participants in the participant's primary language; information reported here included socio-demographics [age, sex, country of origin, marital status, and years of education], health history [frequency of non-steroidal anti-inflammatory drugs use (NSAID; sometimes/daily or rarely/never), history of gout or kidney stones, family history of gout or kidney stones, family history of diabetes, hypertension, or kidney disease], and general work characteristics [payment method (by-the-piece/hourly or salary/other), number of years in US agriculture, training in heat-related illness prevention, use of pesticides at work]. We also inquired if participants had relatives or household members that were also participating, using this information to adjust for possible clustering (non-independence) effects in statistical analyses.

Before and after their work shift on the observation day, blood and urine were collected. Blood was analyzed with the iSTAT Handheld Blood Analyzer Point of Care system with a Chem8+ cartridge (Abbott Laboratories, Abbott Park, IL), measuring sodium, potassium, chloride, BUN (blood urea nitrogen), and creatinine. Urine specific gravity was measured with an ATAGO meter (Atago PAL-10S digital refractometer, Bellevue, Washington). At visits 1 through 4, before work, study staff fitted participants with a monitor worn around the chest (Zephyr™, Boulder, CO) that collected heart rate and physical activity measures every 30 seconds; the monitor was removed when participants returned to the study office after work. Average heart rate and physical activity were calculated for the period between each participant's self-reported work start and stop times.

After work, a FWAF community health worker queried participants (one-to-one) by administering a structured survey that included questions on their work start and stop times, beverage consumption (type and quantities), and heat-related illness (HRI) symptoms (heavy sweating, headache, nausea, dizziness, confusion, muscle cramps, fainting, dysuria) experienced during that workday. The sum of sports drinks, energy drinks, juice, and soda were reported as "ounces of sugary beverages."

The Florida Automated Weather Network (FAWN)[11] is managed by the University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS, which provides rural weather information to agricultural communities. FAWN has 35 monitoring stations which collect weather data every 15 minutes throughout Florida's agricultural communities. FAWN data were obtained from the monitoring station located within each study area (Pierson and Apopka) in which the participants were working. Using the Lu and Romps extended heat index (HI) algorithm based on ambient temperature and relative humidity,[30] mean HI, max HI, and hours spent at HI >=100°$F$ were calculated for each participant's work hours.

The primary kidney function outcomes were pre- and post-work shift estimated glomerular filtration rate (eGFR) and acute kidney injury (AKI). We estimated the glomerular filtration rate using the 2021 CKD-EPI Creatinine Equation,[31] as recommended for U.S. adults by the joint National Kidney Foundation/American Society of Nephrology Task Force[32]. Incident AKI was defined as an increase in creatinine from pre- to post-work shift of at least 50% or ≥0.3 mg/dL in accordance with KDIGO guidelines[25] and as recommended by the First International Research Workshop on Mesoamerican Nephropathy[33].

In addition to age, sex, work type, and time in study, risk factors examined for the primary outcomes of low eGFR and AKI incidence fall into three *a priori* categories: health factors, work conditions, and hydration practices and indicators. Health risk factors included body mass index (BMI), blood pressure (normal [<120 Systolic and <80 Diastolic], elevated 120–139 [Systolic or 80–89 Diastolic], high [≥140 Systolic or ≥90 Diastolic]), A1C ≥5.7 (i.e., prediabetes or diabetes), resting heart rate, sometimes/daily use of NSAIDs, and family history of kidney risk factors (any diabetes /hypertension /kidney disease). Work risk factors included training in HRI prevention (yes/no), occupation as a pesticide applicator (years), workday duration, shade breaks taken, heat exposure (mean HI, max HI, hours at HI ≥100°F), and average heart rate and physical activity (VMU units) during workday. Hydration practices and indicators included total self-reported beverage consumption and average beverage consumption per work hour, sugary beverage consumption, dehydration (urine specific gravity≥1.020 both before and after work), and serum osmolality (mOsm/kg).

Additionally, the effects of primary work type were examined. The two locations were selected because the nature of agricultural work in these two Florida locations is quite distinct. In Apopka, 95% of the recruited participants worked at a nursery while in Pierson, 90% worked in a fernery. Common tasks that nursery workers performed were planting; cutting; trimming; packing; loading and unloading; watering and pruning trees, shrubs, and plants; and moving potted plants and shrubs. Fernery workers mainly cut fern and bundled it into bunches, which they loaded onto a truck. While correspondence between location and primary work type were not absolute, for simplicity, workers from the Apopka cohort will henceforth be referred to as "nursery workers" and the Pierson cohort as "fernery workers." Payment method was not examined as a separate risk factor as it was collinear with primary work type with fernery workers likely to be paid by piece work. This practice is not observed in nursery work.

### Statistical Analysis

Descriptive statistics were presented as % (n) or median (1$^{st}$ quartile, 3$^{rd}$ quartile). Simple differences in characteristics between primary work types at baseline were examined with methods that adjusted for the random effect of household cluster: the R package "lqmm" [linear quantile mixed models][34,35] for median values of continuous variables, generalized linear mixed models for categorical variables.

Before attempting multivariate modelling of the longitudinal data, we used multiple imputation for risk factors having more than 10% missing values. Missing values were assumed missing at random as they were mainly due to machine malfunction. The imputation model included all risk factors, outcomes, and intended interaction terms that would be included in analysis models, plus demographic and clinical auxiliary variables. We conducted the imputation using the R package "mice",[36] which uses fully conditional specification, and employed predictive mean matching (numeric data), logistic regression imputation (binary data, factor with 2 levels), or proportional odds model for (ordered, > 2 levels), as appropriate; 35 imputations and 15 iterations were specified. After examining convergence plots and imputed values, the originally missing *outcome* values were reset to missing.

Because workday heart rate and physical activity were not measured at the final visit, we examined how variable a participant's measurements were over time by calculating the intraclass correlation coefficients (ICC). ICC for mean heart rate was 0.60 for winter and 0.62 for summer (0.55 overall); for mean physical activity it was 0.81 for winter and 0.86 for summer (0.75 overall), indicating low variability. We thus chose to use visit 1 values as the predictor rather than employing a less than optimal imputation of all final visit values. To account for the nested data structure, linear mixed modelling and generalized linear mixed modeling (GLMM) with a random intercept for ID were used for simple and multivariate inference. For predicting pre-work and post-work eGFR, a base model included time, primary work, and their interaction plus covariates age and sex. This simple model was run with all five visits, and again for summer and winter visits separately, dropping the interaction term if it was not significant in the base model. To the summer and winter models, risk factors were added one by one. Risk factors measured at visit 1 were also examined for interaction with time to examine whether they influenced the course of eGFR over time. Models that included imputed risk factors used SAS MIANALYZE[37] to calculate estimates and statistical significance. A similar analytical plan was executed for predicting AKI incidence, except that no winter model was run due to the limited number of cases of AKI. Additionally, the base model included only time, primary work, age, and sex as the interaction term of time by primary work was not significant. The assumptions of logit linearity for continuous predictors and absence of multicollinearity were confirmed.

Analyses were performed with SAS version 9.4 software (Cary, NC) and R 4.3.0. Statistical significance was evaluated using alpha = 0.05.

# RESULTS

## Longitudinal study retention

This study was conducted over 32 months from January 2020 to August 2022, with study visits and workday monitoring conducted in two winters and in three summers during that time. Sixty-seven participants in Apopka, FL, primarily working in nurseries, and forty-eight participants in Pierson, FL, primarily working in ferneries, were initially recruited. As previously reported,[38] more than three quarters of participants were retained over the first two years of the study, with retention decreasing for the final summer visit which occurred more than a year after the previous study visit. Retention at the last visit was higher among Pierson fernery workers (79%) compared with Apopka nursery workers (52%).

## Demographic characteristics

Several differences were identified in the nursery and fernery worker groups (Table 1). While more than two-thirds of the recruited participants working in either setting identified as female, there was a higher percentage (33%) of males among the fernery workers compared to the nursery workers (16%, p=0.03). There were no significant differences in age or in the age at which participants started working in agriculture, but there was a significant difference (p=0.003) in the number of years participants had been working in U.S. agriculture (median 6 in nurseries vs. median 16 in ferneries). Additionally, nearly all (94%) fernery workers claimed Mexican nationality with the remainder being from the U.S., while nursery workers were a less homogenous group (p<0.001) with roots in Mexico (57%), Guatemala (24%), the U.S. (3%), and other countries (16%). A lower percentage (21%) of fernery workers were also single compared to nursery workers (40%, p=0.04). Educational level was similarly low in the two cohorts (median of 8 years, p=0.8).

## Health characteristics

At the initial study visit (January 2020), the median BMI among fernery workers (30.7) was higher than that of nursery workers (28.5, p=0.04), and this pattern remained consistent across study visits (Table S1). Fernery workers also had higher blood pressure (BP; p=0.049); at the initial study visit, 41% of nursery workers had BP readings classified as elevated or hypertensive (>120/80) compared to 59% of fernery workers (Table 1). By the final study visit, the percentage of participants with elevated or hypertensive BP readings had increased in both groups (48% nursery workers, 66% fernery workers), but the distinction between the groups remained (Table S1). No differences were found between the worker groups in diabetes status (based on A1C percent), family or personal history of kidney disease-related medical issues (gout, kidney stones, hypertension, or diabetes), NSAID use, or resting heart rate (Table 1). A seasonal pattern was observed for A1C percent, with slightly higher values in the summers in both worker cohorts (Table S1).

## Work environment and practices

Nearly all (96%) nursery workers were paid by the hour and none by the piece, whereas most fernery workers (73%) were compensated per piece or by a combination of piece and hours (6%) (Table 1). This difference in compensation structure likely contributed to the differences in participants' reports of their workday break practices (p=0.03); among fernery workers, 80% reported taking no breaks or just 1 break during workdays; 46% of nursery workers reported taking 2 or more breaks. Differences in work hours may also have contributed to these differences in breaks. Participants affiliated with nurseries worked longer hours (median 9.0) than did participants affiliated with ferneries (median 7.2) (p<0.001). There were no significant differences between the agricultural settings in participants' reports of working with pesticides or recent training to prevent heat-related illness.

Participants' physical activity also differed between the agricultural settings (Table 1). Fernery workers had a higher average heart rate (median 96.3 bpm) and activity level (median 0.20 VMU) compared with nursery workers (median 91.5 bpm, p=0.04; median 0.11 VMU, p<0.001). A median of .20 VMU is the activity equivalent of someone continuously walking during their whole work shift.[39] Fernery workers were also bending more during their work shifts (p<0.001). These activity differences remained consistent at all timepoints measured (Table 2).

Heat indices were calculated in each location for each study visit day (Figure 1). While there was greater variation in heat indices across study visit days for fernery workers, the mean heat index as well as the number of hours in which the heat index was over 100°F were comparable for both groups. The max heat index did not differ for the first three study visits but was slightly higher for fernery workers at the last two summer study visits.

## Dehydration prevalent among fernery workers

While overall self-reported workday beverage consumption did not differ between fernery and nursery workers, choices of beverages did, with more fernery workers drinking sugary beverages than nursery workers (p=0.002) (Table 1). Sugary beverage intake during work was more common in both groups in the summers than in the winters, but the greater prevalence and higher intake among fernery workers persisted at all study visits (Table S2). Coffee consumption was higher among nursery than fernery workers, but overall, the numbers of participants reporting drinking coffee during work were lower than those reporting drinking sugary beverages or water (Table S2).

Over the course of the study, there was greater evidence of dehydration among fernery workers compared to nursery workers (Table 3). At all but one study timepoint (August 2020 pre-workday), a higher percentage of fernery workers than nursery workers had USG ≥ 1.020, and at all timepoints, more fernery than nursery workers were classified as dehydrated by USG ≥ 1.020 both before and after work shifts (OR 2.1, 95% CI 1.1, 3.8). In the summers, the percentage of workers with USG ≥ 1.020 was higher post-workday than it was pre-workday in both agricultural settings, but the increases in the percentage of dehydrated workers pre- to post-workday were higher among fernery workers than nursery workers. Furthermore, in the summers, markedly higher percentages of fernery workers compared to nursery workers were classified as severely dehydrated (USG ≥ 1.030) post-workday (25%, 11%, and 18% vs 2%, 4%, and 9%, respectively (OR 4.9, 95% CI 1.6, 14.8). At all but one timepoint, higher percentages of fernery workers compared to nursery workers also met the criteria for hyperosmolality post-workday.

## Pre-workday eGFR slightly higher in fernery vs. nursery workers

Pre-workday eGFR values adjusted for sex and age of participants remained more consistent across the study than did post-workday eGFR values (Figure 3). There was no significant interaction between work season and primary work type, as there was with post-workday eGFR, but there were significant main effects, with pre-workday eGFR values slightly lower in the summers (beta −1.5, 95% CI −2.7, −0.3) and slightly higher in fernery compared with nursery workers (beta 4.1, 95% CI 1.4, 6.9). Pre-work eGFR < 90 was only seen in a single participant during the study (Table 3).

## Increasing AKI and declining post-workday eGFR in fernery workers

Patterns of AKI across the study differed between nursery and fernery workers (Figure 2, Table 3). At all but one timepoint (July 2021), about 10% of nursery workers met the criteria for AKI post-work shift. At all but one timepoint (Aug 2020), more than 20% of fernery workers met the criteria for AKI post-work shift, and this percentage increased progressively over the last three study timepoints from 21% in January 2021 to 43% in August 2022 (OR 8.1 for fernery workers in summer 2021 and 12.6 in summer 2022 relative to summer 2020 compared with 2.4 and 1.1 for nursery workers, respectively, Table S3). Besides agricultural setting, none of the demographic factors, health factors, work conditions, or hydration measures collected in this study were significantly associated with summer AKI(Table S3).

Estimated GFR levels calculated pre- and post-work shift also differed across the study for workers in the two agricultural settings (Table 3, Figure 3). After adjustment for sex and age of the participants, post-workday eGFR values for fernery workers were higher than for nursery workers at the first three study timepoints (winter 2020, summer 2020, winter 2021), but, in alignment with AKI results, post-workday eGFR values for fernery workers dropped below nursery workers at the last two summer timepoints (Figure 3, Table 4). For fernery workers, comparing base summer 2020 to the two following summers showed substantial decline in eGFR (2021 beta −9.3, 95% CI −16.9, −1.7; 2022 beta −10.5, 95% CI −18.1, −2.9) that was not observed for nursery workers (2021 beta −2.6, 95% CI −7.5, 2.2; 2022 beta 2.8, 95% CI −2.3, 7.9) (Table 4). At these timepoints, we also observed higher percentages of fernery workers with post-workday eGFR < 90 than had been seen at previous timepoints or were ever observed among nursery workers in this study (Table 3).

Our primary predictor, heat exposure, significantly impacted summer post-workday eGFR; for every degree increase in average heat index, post-workday eGFR declined by 0.5 units (p=0.036), and controlling for it in the model revealed significant declines in eGFR from summer 2020 to summer 2021 in nursery workers (beta −6.0, 95% CI −11.7, −0.3) while deattenuating the effect in fernery workers for the same time period (beta −5.8, 95% CI −14, 2.3) (Table 4). Similar effects were observed when accounting for the number of work hours in which the heat index was above 100°F. A significant negative association (p=0.024) was identified between summer post-workday eGFR and the volume of beverage consumption during the workday independent of agricultural setting. Besides age, no other risk factors were significantly associated with this outcome, nor were they confounders of the relationship between work type and time.

Post-workday eGFR in the winters appeared to have a different relationship with predictors evaluated in this study (Table 5). There was not a clear effect of agricultural setting nor evidence of decline between winter 2020 and winter 2021. Other than age, the only predictor that was significantly associated with winter post-workday eGFR was serum osmolality, with eGFR declining 1 unit for every unit increase in serum osmolality (95% CI −1.5, −0.5).

There were no appreciable differences longitudinally across the summers or the winters (Tables 6 and 7, respectively). Resting heart rate, NSAID use, and work applying pesticides were significant predictors of summertime pre-work eGFR. Every beat per minute increase in resting heart rate was associated with an increase of 0.1 units in pre-workday eGFR (95% CI 0.1, 0.2, p=0.001). Participants who reported using NSAIDs more frequently had higher pre-workday eGFR (beta 2.2, 95% CI 0, 4.3, p=0.049). Each year of occupational pesticide use was associated with a decline of 0.4 units in pre-workday eGFR (95% CI −0.9, 0, p=0.042). Beyond age and sex, no other risk factors assessed were significantly associated with summertime eGFR, nor were they confounders of the relationship between pre-workday eGFR and work type (Table 6). Additionally, other than age, none of the risk factors assessed was significantly associated with wintertime pre-workday eGFR (Table 7).

## DISCUSSION

In this longitudinal study of two agricultural communities in Florida, we found differences in their levels of renal dysfunction. Pre-workday eGFR in both communities was slightly lower in the summers. The study participants in Pierson, who worked almost exclusively in fernery operations, had slightly higher pre-workday eGFR compared with participants from Apopka, who worked primarily in agricultural nurseries, and this did not vary greatly over time. In contrast, post-workday eGFR for fernery workers, which had been slightly higher than for nursery workers in previous study seasons, dropped below that for nursery workers at the last two summer timepoints. Fernery workers also had a high rate of AKI post-workday when they were first measured in 2020 (21%), and the rate had more than doubled by the end of the study (43%). In contrast, in Apopka, AKI developed in approximately 10–11% of participants, and the rate was stable over time.

Fernery workers (Pierson, Fl) have several risk factors that may place them at increased risk of AKI and lower post-work eGFR compared to nursery workers (Apopka, Fl). Fernery workers are primarily compensated by the piece rate system that likely contributes to them taking fewer rest breaks (0–1 rest break) and have higher physical activity, whereas the nursery workers are primarily hourly workers, more of them took 2 rest breaks, and their physical activity was lower. Furthermore, the fernery workers consumed more sugary drinks, specifically in the summers, compared to the nursery workers.

We observed a significant negative association (p=0.024) between summer post-workday eGFR and the volume of fluid consumption during the workday independent of agricultural setting. Although workers in both locations were consuming more fluid in the summer, the average fluid consumption per hour was between 8 and 12 ounces, whereas the recommended amount for those working strenuously in the heat is 24–32 ounces per hour. Workers who were drinking more were probably under more heat stress, but the amount of fluid they were drinking was not enough to keep them hydrated. Heat index was a significant predictor of post-work eGFR, and the fernery workers experienced slightly higher heat index with some differences in max heat index; however, the mean was quite similar in both groups. Including heat index as a covariate in analytical models with AKI or post-workday eGFR as outcomes did not markedly impact the significant relationship with work type, indicating that the difference between the worker groups was not all attributable to heat index.

The fernery workers in Florida have similar risk factors as agricultural workers with CKDu in Mesoamerica, such as being compensated by the piece-rate system, intense physical exertion, high ambient temperature, dehydration, and increased consumption of sugary drinks.[7,18–20,40] Degradation of renal function over time has been documented among Mesoamerican sugarcane workers[9–11]. While our assessments of pre-workday eGFR suggest that Florida fernery workers did not experience irreversible declines in kidney function over the 32-month duration of this study, the marked drop in post-work eGFR at the latest study timepoints and the progressive increase in the percentage of fernery workers meeting the criteria for AKI after work raise concern. AKI and chronic degradation of renal function have been described as risk factors for the development of CKD.[17,41,42] However, most of these studies have focused on patients developing AKI in the hospital. One study in Guatemalan sugarcane workers, however, found that workers who experienced the greatest changes in serum creatinine levels – the marker used to calculate eGFR and define AKI in this study – over the course of their work shifts had more pronounced declines in eGFR over a harvest season[20]. To our knowledge, this is the first study of U.S. agricultural workers evaluating renal function over time, and we observed an increase in cross-shift variation in serum creatinine among fernery workers over the course of several harvest seasons. It is possible that recurrent episodes of AKI could contribute to the subsequent development of CKD, and eventually to ESRD. A longer period of follow-up will be necessary to determine whether the participants in our study who developed AKI progress to CKD. Established CKD inexorably progresses to worsening renal function and ultimately to the need for renal replacement therapy.

The cause of renal dysfunction, both CKDu and AKI, among agricultural workers remains unclear, but factors including exposure to high ambient temperatures, intense physical exertion, elevated core body temperature, and dehydration continue to be implicated.[7,18–20] It has also been postulated that the cause of renal dysfunction among agricultural workers may be multi-factorial and that pesticides may have an important role to play.[18,43] A recent study in Mexico assessed kidney function over a six-month harvest season in 50 agricultural workers who labored in organic fields, 51 agricultural workers in conventional fields, and 50 office workers within the same region.[18] Although the organic and conventional groups had declines in eGFR, the conventional group with more exposure to pesticides had a more significant decline.[18] The office worker group did not show a decline in eGFR.[18] We have previously reported that while fernery workers perceive that they have high levels of pesticide exposure, urinary markers of organophosphate pesticides are actually higher among nursery workers.[44] In this study, we identified a significant inverse association between years of occupational pesticide exposure and pre-workday eGFR, and pre-workday eGFR was lower among nursery workers, supporting the idea that pesticides could negatively impact kidney function. Additionally, we identified a positive association between NSAID use and pre-workday eGFR, with participants who reported taking NSAIDs more frequently having higher pre-workday eGFR. NSAIDs have the potential for nephrotoxicity and have been proposed as a risk factor for the development of CKDu among agricultural workers, but significant associations have rarely been identified. Our results in fact suggest that NSAIDs could have some benefit for baseline kidney function, perhaps combatting inflammatory mechanisms contributing to AKI[45]. Further studies are needed to validate these findings and clarify the role of these risk factors in renal degradation.

In the meantime, minimization of risk factors during the workday to reduce the risk of AKI and the future development of CKD seems prudent. Hydrating with electrolyte solutions has been reported as a potential measure to reduce the development of AKI and renal dysfunction in agricultural workers.[46,47] The piece-rate compensation system seems to be the factor that incentivizes workers to eschew breaks and better hydration with the goal of earning more money, which appears to increase risk of renal dysfunction. Thus, it is necessary to re-evaluate the piece-rate system and integrate safeguards to protect workers or eliminate the system altogether. Further research is also needed to find more evidence-based solutions to protect workers from kidney dysfunction.

### Strengths and Limitations:

A few workers from each location reported working in an agricultural environment other than a nursery or fernery. Furthermore, it is not uncommon for agricultural workers to assume different responsibilities and work in different environments over time. This is also a reflection of the different economic strategies that agricultural workers rely on over time to secure a livelihood under precarious job security situations. Understanding the dynamic nature of this occupation, we decided not to restrict this study to participants only working at a fernery or nursery, even though this necessitated an imperfect comparison of these agricultural settings.

Strengths of this study are that we recorded beverage consumption with a post-workday structured interview using props to demonstrate sizes; we followed workers for 32 months and had good retention both in summer and winter visits; and had a good range of heat indices that strengthened power to detect effect. Although we were able to examine many of the risk factors proposed in the literature, we do not know the types of pesticides or the level of exposure. There also was not much power to detect effects for AKI because of the relatively small number of events. It should also be noted that the classification of

AKI was based on changes in serum creatinine, consistent with standard clinical practice, and not confirmed by additional clinical testing such as imaging or biopsies. Temperature and humidity are not from the work sites themselves and may not account for the micro-environment of the worker (inside greenhouse, under shade cloth, etc.), nor was core body temperature assessed in this study. This is a limitation since it is a combination of environmental heat exposure as well as physical exertion which results in hyperthermia and the physiological responses that increase the risk of AKI.

## CONCLUSION

To our knowledge, this is the first study of agricultural workers in the U.S. evaluating renal function over time. We found relatively stable pre-workday eGFR over the course of the study, with slight decreases in summers, but found increasing incidence of AKI and lower eGFR post-workday as time progressed among the piece-rate workers who are incentivized to forgo rest breaks and hydration, even with high ambient temperature. Workers became more dehydrated in summer despite increased fluid consumption because the increase was not commensurate with their need. Further research is needed to find evidence-based solutions to improve hydration and protect workers from kidney dysfunction.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Funding Sources for ALL Authors:

This study was funded by a research grant from the National Institute for Occupational Safety & Health (grant number CDC/NIOSH R01OH011782) and the National Institute of Nursing Research (NIH/NINR K23NR020356).

## Data Availability:

Data available on request from the authors

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**Bulleted Learning:**

- Differentiate risk factors for AKI and renal function between fernery workers (piece-rate compensation) and nursery workers (hourly compensation).
- Recognize that piece-rate workers may be at increased risk of AKI and renal dysfunction.

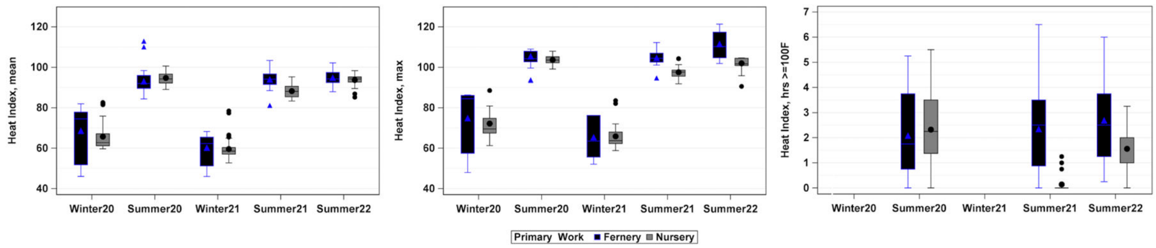


**Figure 1. Heat indices largely comparable in both agricultural settings**

At each study visit, the distribution of participants' work shift heat exposure: mean and max heat index experienced during their work shift and number of hours in which the heat index was above 100°F. Boxplots summarize values for all participants, with the line inside the box representing the median and the symbol inside the box representing the mean. Weather data obtained from the Florida Automated Weather Network (FAWN) monitoring stations. Heat index calculated using Lu and Romps extended heat index algorithm based on ambient temperature and relative humidity.

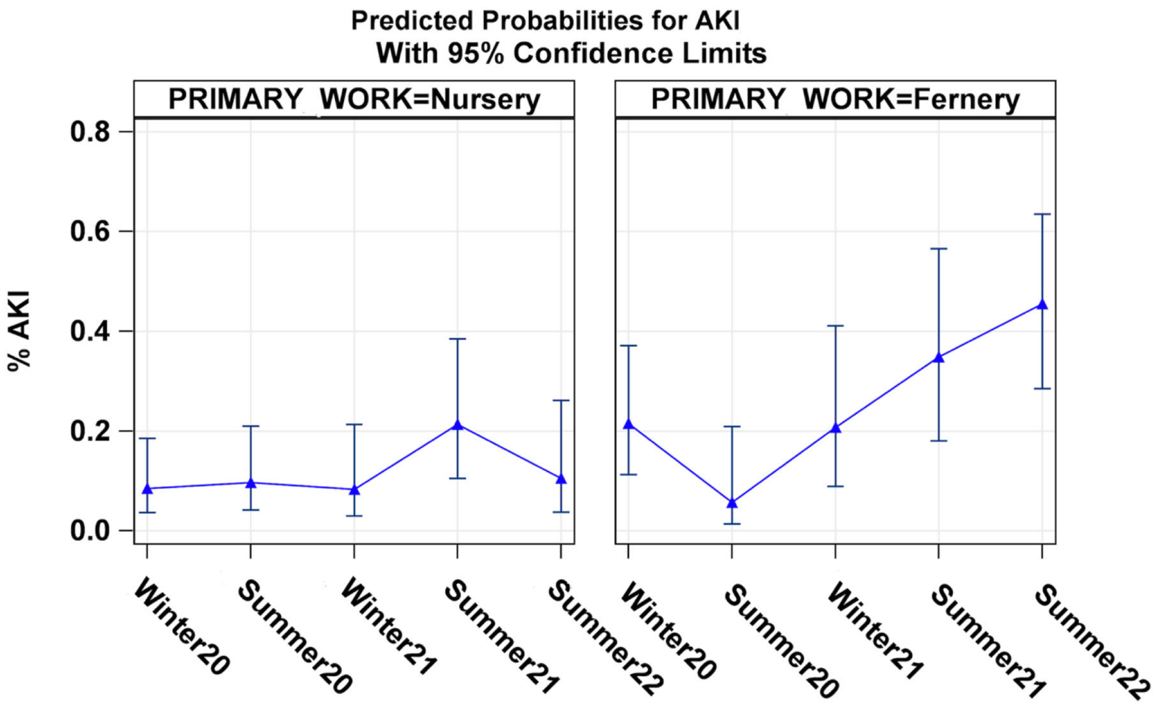


**Figure 2. Acute kidney injury (AKI) more prevalent among fernery workers**

Percentage of participants meeting the criteria for AKI (an increase in serum creatinine from before to after work shift of at least 50% or ≥ 0.3 mg/dL) at each timepoint in each agricultural setting as predicted by generalized linear mixed model containing the following variables: primary work type, timepoint, the interaction of primary work type and timepoint, age, and sex. Error bars reflect 95% Confidence Limits.

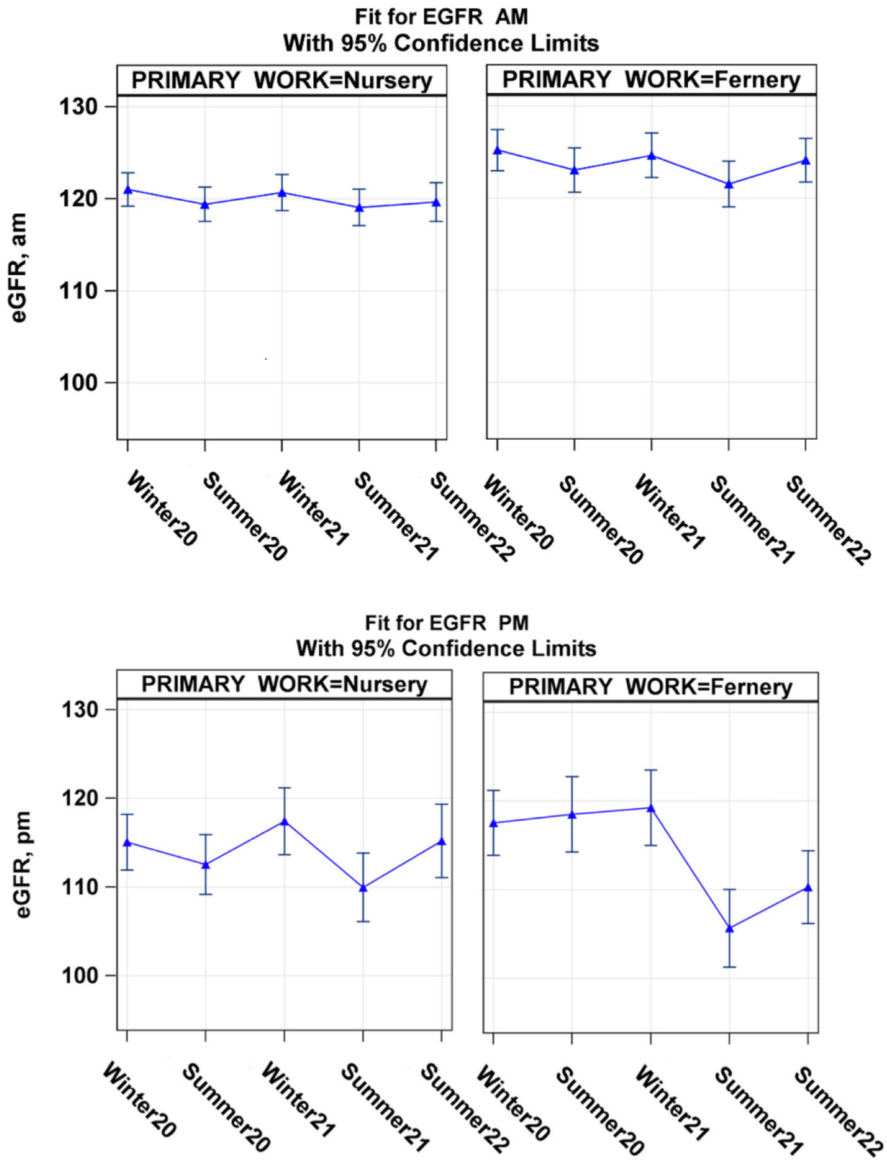


**Figure 3. Longitudinal and seasonal dynamics of pre- and post-work estimated kidney function**

Average pre- and post-work eGFR calculated from serum creatinine values at each timepoint in each agricultural setting as predicted by linear mixed model containing the following variables: primary work type, timepoint, the interaction of primary work type and timepoint, age, and sex. Error bars reflect 95% Confidence Limits.

**TABLE 1.**

Participant Personal and Work Characteristics at Initial Visit, by primary work. OHEaRD Study Jan2020

| Characteristic | N | Overall[1], N = 115 | Nursery[1], N = 67 | Fernery[1], N = 48 | p-value[2] |
|---|---|---|---|---|---|
| ***Demographics*** | | | | | |
| **Age, yrs** | 115 | 38.9 (33.4, 44.5) | 37.6 (33.4, 43.2) | 41.1 (33.7, 46.0) | 0.1 |
| **Sex** | 115 | | | | 0.03 |
| Male | | 23% (27) | 16% (11) | 33% (16) | |
| Female | | 77% (88) | 84% (56) | 67% (32) | |
| **Nationality** | 115 | | | | <0.001 |
| Mexico | | 72% (83) | 57% (38) | 94% (45) | |
| Guatemala | | 14% (16) | 24% (16) | 0% (0) | |
| USA | | 4% (5) | 3% (2) | 6% (3) | |
| Other | | 10% (11) | 16% (11) | 0% (0) | |
| **Education, yrs** | 114 | 8.0 (6.0, 10.0) | 8.0 (6.0, 11.0) | 8.0 (6.0, 9.0) | 0.8 |
| **Marital Status** | 115 | | | | 0.04 |
| Coupled | | 68% (78) | 60% (40) | 79% (38) | |
| Single | | 32% (37) | 40% (27) | 21% (10) | |
| ***Health-Related*** | | | | | |
| **BMI** | 115 | 29.1 (25.7, 33.4) | 28.5 (24.7, 32.2) | 30.7 (27.0, 33.8) | 0.04 |
| **Heart rate, resting, bpm** | 115 | 73.0 (66.5, 81.0) | 73.0 (66.0, 82.5) | 74.0 (68.0, 79.2) | 0.5 |
| **Blood pressure** | 107 | | | | 0.049 |
| <120/80 | | 52% (56) | 59% (38) | 42% (18) | |
| 120–139 or 80–89 | | 34% (36) | 25% (16) | 47% (20) | |
| 140+ or 90+ | | 14% (15) | 16% (10) | 12% (5) | |
| **A1C** | 114 | | | | 0.1 |
| normal | | 84% (96) | 79% (52) | 92% (44) | |
| prediabetic | | 13% (15) | 18% (12) | 6% (3) | |
| diabetic | | 3% (3) | 3% (2) | 2% (1) | |
| **NSAID, sometimes/daily** | 115 | 14% (16) | 13% (9) | 15% (7) | 0.9 |
| **Hx Gout/Kidney Stones** | 114 | 4% (4) | 4% (3) | 2% (1) | 0.5 |
| **Family Hx Gout/Kidney Stones** | 108 | 13% (14) | 15% (9) | 11% (5) | 0.5 |
| **Family Hx DB/HTN/KD** | 110 | 52% (57) | 52% (33) | 51% (24) | 0.9 |
| ***Work-related*** | | | | | |
| **Work type** | 113 | | | | |
| Fernery | | 38% (43) | 0% (0) | 90% (43) | <0.001 |
| Nursery | | 56% (63) | 95% (62) | 2% (1) | |
| Other | | 6% (7) | 5% (3) | 8% (4) | |
| **Work hours** | 113 | 8.5 (7.0, 9.5) | 9.0 (8.5, 9.5) | 7.2 (6.0, 8.5) | <0.001 |
| **Age started in agriculture** | 115 | 20.0 (17.0, 26.0) | 21.0 (15.5, 29.0) | 19.0 (17.0, 25.0) | 0.4 |
| **Working in US agriculture, yrs** | 114 | 11.0 (4.0, 18.0) | 6.0 (2.5, 14.0) | 16.0 (10.0, 22.5) | 0.003 |
| **Payment** | 115 | | | | <0.001 |
| By the piece | | 30% (35) | 0% (0) | 73% (35) | |

| Characteristic | N | Overall[1], N = 115 | Nursery[1], N = 67 | Fernery[1], N = 48 | p-value[2] |
|---|---|---|---|---|---|
| By the hour | | 64% (74) | 96% (64) | 21% (10) | |
| Combination piece/hour | | 3% (4) | 1% (1) | 6% (3) | |
| Salary | | 2% (2) | 3% (2) | 0% (0) | |
| **Took breaks** | 113 | | | | 0.03 |
| None | | 35% (39) | 31% (20) | 40% (19) | |
| One | | 30% (34) | 23% (15) | 40% (19) | |
| Two | | 33% (37) | 43% (28) | 19% (9) | |
| Three or more | | 3% (3) | 3% (2) | 2% (1) | |
| **Took shade breaks** | | 58% (65) | 63% (41) | 50% (24) | 0.2 |
| **HRI training in past yr** | 115 | 33% (38) | 31% (21) | 35% (17) | 0.6 |
| **Works with pesticides** | 115 | 8% (9) | 12% (8) | 2% (1) | 0.1 |
| **Heart rate, avg during work, bpm** | 105 | 94.5 (87.9, 100.8) | 91.5 (86.4, 99.4) | 96.3 (90.2, 104.4) | 0.04 |
| **Activity, avg during work, VMU in g** | 108 | 0.13 (0.10, 0.19) | 0.11 (0.09, 0.13) | 0.20 (0.15, 0.24) | <0.001 |
| **Posture, avg during work, degrees from vertical** | 108 | 7 (−3, 27) | 0 (−4, 8) | 26 (10, 37) | <0.001 |
| ***Hydration*** | | | | | |
| **Beverages, oz** | 113 | 44.0 (30.0, 64.0) | 40.0 (24.0, 64.0) | 48.0 (36.5, 64.0) | 0.2 |
| **Sugary beverages, oz** | 113 | 0.0 (0.0, 12.0) | 0.0 (0.0, 8.0) | 12.0 (0.0, 16.0) | 0.002 |

[1] % (n) or median (1st quartile, 3rd quartile)

[2] Differences tested using linear quantile mixed models (continuous variables) or generalized linear mixed models (categorical variables), unless the random effect of household cluster was negligible. In the latter case, simple linear regression or chi square tests were conducted.

**TABLE 2.**

Workday Physical Activity Summaries Based on 30-second Epoch Continuous Monitoring.

| | | Jan2020[1] | July2020[1] | Jan2021[1] | July2021[1] |
|---|---|---|---|---|---|
| **Fernery** | | **N = 45[2]** | **N = 28** | **N = 35** | **N = 14** |
| | **Activity, mean** | 0.20 (0.15, 0.24) | 0.15 (0.13, 0.22) | 0.20 (0.14, 0.25) | 0.20 (0.16, 0.24) |
| | **Posture, mean** | 26 (10, 37) | 10 (0, 24) | 26 (−3, 41) | 31 (14, 40) |
| | **Steps, Walking** | 3,407 (2,681, 6,086) | 3,180 (1,906, 5,442) | 4,141 (2,381, 6,892) | 2,381 (2,057, 3,830) |
| | **Steps, Running** | 15 (6, 25) | 30 (8, 78) | 15 (6, 52) | 10 (4, 29) |
| | **Steps, Walking+Running** | 3,463 (2,700, 6,107) | 3,190 (1,910, 6,110) | 4,152 (2,384, 7,046) | 2,422 (2,074, 3,848) |
| | **Heart rate, mean** | 96 (90, 104) | 95 (87, 108) | 96 (90, 104) | 104 (95, 116) |
| **Nursery** | | **N = 63[2]** | **N = 46** | **N = 47** | **N = 41** |
| | **Activity, mean** | 0.11 (0.09, 0.13) | 0.10 (0.08, 0.14) | 0.10 (0.08, 0.13) | 0.11 (0.08, 0.13) |
| | **Posture, mean** | 0 (−4, 8) | −1 (−4, 4) | −2 (−5, 4) | 0 (−5, 5) |
| | **Steps, Walking** | 7,574 (4,586, 10,052) | 5,712 (4,415, 10,370) | 5,380 (4,279, 9,794) | 6,672 (3,871, 9,907) |
| | **Steps, Running** | 58 (28, 156) | 58 (14, 126) | 48 (26, 112) | 77 (29, 134) |
| | **Steps, Walking+Running** | 7,779 (4,655, 10,361) | 5,784 (4,425, 10,424) | 5,609 (4,308, 9,864) | 6,934 (3,903, 9,984) |
| | **Heart rate, mean** | 92 (86, 99) | 94 (87, 102) | 91 (83, 98) | 91 (84, 100) |

[1]Median (IQR)

[2]Monitor files were included in calculations if at least 80% of the workday was captured. Additional missingness of $m_{Fernery}$=19, $m_{Nursery}$=27 records for steps at visit 1 due to technical issues.

Activity was not measured during the 2022 season.

Summer data are shaded.

## TABLE 3.

Urine and Serum Characteristics, OHEaRD Study Jan2020-AUG2022.

| | Nursery | | | | | Fernery | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristic** | **Jan2020[1] N = 67** | **Aug2020[1] N = 60** | **Jan2021[1] N = 50** | **Jul2021[1] N = 52** | **Aug2022[1] N = 35** | **Jan2020[1] N = 48** | **Aug2020[1] N = 39** | **Jan2021[1] N = 37** | **Jul2021[1] N = 36** | **Aug2022[1] N = 38** |
| **USG >=1.020, am** | 30% (19) | 45% (25) | 24% (12) | 39% (20) | 37% (13) | 40% (17) | 44% (16) | 49% (18) | 53% (19) | 50% (19) |
| **USG >=1.020, pm** | 28% (17) | 68% (40) | 28% (14) | 44% (22) | 49% (17) | 43% (18) | 78% (28) | 41% (14) | 67% (24) | 66% (25) |
| **USG >=1.020, am & pm** | 14% (8) | 33% (18) | 10% (5) | 27% (13) | 23% (8) | 23% (9) | 39% (13) | 32% (11) | 44% (16) | 39% (15) |
| **USG >=1.030, am** | 3% (2) | 0% (0) | 0% (0) | 2% (1) | 6% (2) | 2% (1) | 3% (1) | 5% (2) | 3% (1) | 5% (2) |
| **USG >=1.030, pm** | 7% (4) | 2% (1) | 4% (2) | 4% (2) | 9% (3) | 2% (1) | 25% (9) | 6% (2) | 11% (4) | 18% (7) |
| **Serum Osm, am** | | | | | | | | | | |
| Hyper-osmolality[2] | 41% (25) | 33% (18) | 27% (12) | 61% (27) | 57% (20) | 49% (23) | 32% (11) | 21% (7) | 50% (15) | 43% (16) |
| **Serum Osm, pm** | | | | | | | | | | |
| Hyper-osmolality[2] | 14% (9) | 30% (17) | 14% (6) | 49% (20) | 40% (14) | 40% (19) | 33% (11) | 18% (6) | 48% (15) | 46% (17) |
| **AKI** | 10% (6) | 11% (6) | 10% (4) | 24% (9) | 11% (4) | 21% (10) | 6% (2) | 21% (6) | 33% (9) | 43% (16) |
| **eGFR, am** | | | | | | | | | | |
| Median | 121 | 121 | 122 | 118 | 119 | 124 | 119 | 124 | 121 | 124 |
| (IQR) | (117, 128) | (115, 126) | (117, 126) | (113, 125) | (114, 126) | (116, 128) | (115, 126) | (118, 134) | (114, 128) | (115, 131) |
| **eGFR, pm** | | | | | | | | | | |
| Median | 117 | 117 | 119 | 115 | 117 | 117 | 116 | 118 | 114 | 113 |
| (IQR) | (112, 125) | (108, 123) | (112, 125) | (105, 118) | (110, 121) | (111, 127) | (110, 121) | (114, 126) | (82, 122) | (92, 124) |
| **eGFR <90, am** | 0% (0) | 0% (0) | 0% (0) | 2% (1) | 0% (0) | 0% (0) | 0% (0) | 0% (0) | 0% (0) | 0% (0) |
| **eGFR <90, pm** | 3% (2) | 5% (3) | 5% (2) | 12% (5) | 0% (0) | 8% (4) | 0% (0) | 0% (0) | 28% (9) | 14% (5) |

[1] % (n) or median (1st quartile, 3rd quartile)

[2] (>295 mOsm/kg)

Summer values are shaded.

## TABLE 4.

Summertime Predictors of Post-work eGFR Evaluated using Mixed Models with the Base Model containing Primary Work Type, Timepoint, and their Interaction, Controlling for Sex and Age.

| MODEL[1] | Intercept | Primary Work Type | Nursery × Time | | Fernery × Time | | Sex | Age | Additional Covariate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Summer20 (ref=Nursery) | Summer21 (ref=Summer20) | Summer22 (ref=Summer20) | Summer21 (ref=Summer20) | Summer22 (ref=Summer20) | (ref=female) | (cent40[4]) | | |
| | Estimated Beta (95% confidence interval)[2] | | | | | | | | | p-value[3] |
| **Base model** | 107.9 (102.5, 113.4) | **5.8 (0.2, 11.4)** | −2.6 (−7.5, 2.2) | 2.8 (−2.3, 7.9) | **−9.3 (−16.9, −1.7)** | **−10.5 (−18.1, −2.9)** | 4 (−1, 9) | **−1.1 (−1.3, −0.8)** | | |
| **+ Health Factors** | | | | | | | | | | |
| BMI cent30[4] | 107.7 (102.2, 113.1) | **6.3 (0.7, 12)** | −2.5 (−7.4, 2.3) | 2.9 (−2.2, 8) | **−9.6 (−17.2, −2)** | **−10.6 (−18.2, −3)** | 4.2 (−0.8, 9.1) | **−1 (−1.3, −0.7)** | −0.2 (−0.6, 0.1) | 0.22 |
| BP 120–139 or 80–89 (ref=<120/80) | 107.4 (101.5, 113.3) | 5.7 (0, 11.4) | −2.8 (−7.8, 2.1) | 2.8 (−2.4, 7.9) | **−8.7 (−16.5, −0.9)** | **−10.4 (−18.1, −2.8)** | 4.2 (−0.9, 9.3) | **−1.1 (−1.4, −0.8)** | 0.8 (−3.2, 4.9) | 0.687 |
| BP140+ or 90+ (ref=<120/80) | | | | | | | | | 0.7 (−4.7, 6.1) | 0.798 |
| A1C >=5.7 at V1[5] | 107.2 (101.5, 112.9) | **6.3 (0.6, 12)** | −2.6 (−7.5, 2.3) | 3 (−2.2, 8.1) | **−9.3 (−16.9, −1.7)** | **−10.7 (−18.3, −3)** | 4.1 (−0.9, 9.1) | **−1.1 (−1.3, −0.8)** | 2.0 (−3.4, 7.3) | 0.461 |
| Resting heart rate | 108.6 (95.6, 121.6) | **5.8 (0.2, 11.5)** | −2.7 (−7.6, 2.2) | 2.7 (−2.6, 8) | **−9.3 (−16.9, −1.6)** | **−10.1 (−17.8, −2.4)** | 4.2 (−0.9, 9.2) | **−1.1 (−1.3, −0.8)** | 0 (−0.2, 0.2) | 0.899 |
| NSIAD use, sometimes or daily | 108 (102.5, 113.4) | **5.8 (0.2, 11.4)** | −2.7 (−7.6, 2.2) | 2.8 (−2.3, 7.9) | **−9.3 (−16.9, −1.6)** | **−10.5 (−18.1, −2.9)** | 4.1 (−0.9, 9) | **−1.1 (−1.3, −0.8)** | −0.4 (−5.2, 4.4) | 0.874 |
| Family hx kidney risk factors[6] | 107.3 (101.1, 113.6) | **6 (0.1, 11.8)** | −3.2 (−8.3, 1.9) | 2.7 (−2.6, 8) | **−9.2 (−17.1, −1.4)** | **−10.1 (−17.9, −2.3)** | 4.0 (−1.2, 9.2) | **−1.1 (−1.4, −0.8)** | 1.0 (−3, 5.1) | 0.618 |
| **+ Work Conditions** | | | | | | | | | | |
| Training in HRI prevention | 107.3 (101.8, 112.8) | 5.5 (−0.2, 11.1) | −2.7 (−7.6, 2.1) | 2.6 (−2.5, 7.8) | **−9.3 (−16.9, −1.8)** | **−10.3 (−17.9, −2.7)** | 3.8 (−1.1, 8.8) | **−1.1 (−1.3, −0.8)** | 2.7 (−1.4, 6.8) | 0.194 |

| MODEL[1] | Intercept | Primary Work Type | Nursery × Time | | Fernery × Time | | Sex | Age | Additional Covariate | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Summer20 (ref=Nursery) | Summer21 (ref=Summer20) | Summer22 (ref=Summer20) | Summer21 (ref=Summer20) | Summer22 (ref=Summer20) | (ref=female) | (cent40[4]) | | |
| | Estimated Beta (95% confidence interval)[2] | | | | | | | | | p-value[3] |
| Pesticide use, years | 110 (104, 116) | 5.4 (−0.3, 11) | −2.7 (−7.6, 2.1) | 2.7 (−2.5, 7.8) | **−9.3 (−16.8, −1.7)** | **−10.4 (−18, −2.9)** | 2.2 (−3.2, 7.7) | **−1.0 (−1.3, −0.8)** | −0.5 (−1.2, 0.1) | 0.127 |
| Workday duration, hours | 108.1 (102.5, 113.7) | 5.6 (−0.5, 11.6) | −2.7 (−7.5, 2.2) | 2.8 (−2.3, 7.9) | **−9.3 (−16.9, −1.7)** | **−10.5 (−18.1, −2.8)** | 3.9 (−1.1, 9) | **−1.1 (−1.3, −0.8)** | −0.1 (−1.1, 0.9) | 0.812 |
| Shade breaks taken | 106.8 (101, 112.6) | **5.9 (0.4, 11.5)** | −2.8 (−7.6, 2) | 2.6 (−2.4, 7.6) | **−8.1 (−15.6, −0.6)** | **−10.2 (−17.7, −2.8)** | 3.4 (−1.6, 8.4) | **−1.0 (−1.3, −0.8)** | 2.8 (−0.7, 6.3) | 0.115 |
| Heat Index mean, cent90[4] | 109.8 (104.1, 115.5) | 5.1 (−0.5, 10.7) | **−6.0 (−11.7, −0.3)** | 2.1 (−2.9, 7.2) | −5.8 (−14, 2.3) | **−9.1 (−16.7, −1.6)** | 4.6 (−0.4, 9.7) | **−1.0(−1.3, −0.8)** | **−0.5 (−0.9, 0)** | **0.036** |
| Heat Index, hrs >=100°F | 111.3 (105.2, 117.5) | 5.5 (−0.1, 11.0) | **−5.7 (−11.3, −.1)** | 1.8 (−3.5, 7.0) | −6.0 (−14.1, 2.1) | **−8.7 (−16.5, −1.0)** | 3.8 (−1.1, 8.7) | **−1.0(−1.3, −0.8)** | **−1.3 (−2.5, −0.1)** | **0.030** |
| HR mean at V1[5], cent95[4] | 107.5 (102.1, 113) | **6.3 (0.6, 12)** | −2.6 (−7.5, 2.2) | 2.8 (−2.3, 7.9) | **−9.4 (−17, −1.8)** | **−10.5 (−18.1, −2.9)** | 4.2 (−0.8, 9.1) | **−1.1 (−1.4, −0.8)** | −0.1 (−0.3, 0.1) | 0.436 |
| Workday Physical Activity mean at V1[5] | 109.5 (100.7, 118.3) | 6.7 (−0.1, 13.5) | −2.7 (−7.5, 2.2) | 2.8 (−2.3, 8) | **−9.2 (−16.8, −1.6)** | **−10.5 (−18.1, −2.9)** | 3.6 (−1.5, 8.7) | **−1.1 (−1.4, −0.8)** | −11.6 (−62.5, 39.4) | 0.652 |
| HRI symptoms | 108.5 (103, 114.1) | 5.6 (−0.1, 11.2) | −2.8 (−7.6, 2.1) | 2.8 (−2.3, 7.9) | **−8.8 (−16.4, −1.2)** | **−10.6 (−18.1, −3)** | 4.2 (−0.8, 9.3) | **−1.1 (−1.3, −0.8)** | −1.0 (−3, 1) | 0.307 |
| **+ Hydration** | | | | | | | | | | |
| Beverage consumption, oz. cent64[4] | 110.5 (104.7, 116.4) | 5.6 (0, 11.1) | −2.8 (−7.6, 2) | 3.3 (−1.8, 8.4) | **−8.8 (−16.3, −1.3)** | **−10.1 (−17.6, −2.6)** | 1.5 (−3.9, 6.9) | **−1.1 (−1.3, −0.8)** | **−0.06 (−0.1, 0)** | **0.024** |
| Sugary drinks consumption, oz | 108.1 (102, 114.2) | 5.6 (−0.5, 11.6) | −2.7 (−7.6, 2.3) | 2.8 (−2.4, 8) | **−9.3 (−17, −1.7)** | **−10.5 (−18.1, −2.8)** | 3.9 (−1.2, 9) | **−1.1 (−1.3, −0.8)** | 0 (−0.1, 0.1) | 0.999 |
| Dehydration, both am & pm[7] | 109.2 (103.4, 114.9) | **6.1 (0.5, 11.8)** | −2.7 (−7.5, 2.1) | 2.6 (−2.5, 7.7) | **−9.2 (−16.7, −1.7)** | **−10.4 (−17.9, −2.9)** | 3.5 (−1.6, 8.5) | **−1.1 (−1.3, −0.8)** | −2.6 (−6.3, 1.1) | 0.174 |
| Serum Osmolality, cent295[4] | 108.3 (102.9, 113.6) | **5.7 (0.2, 11.3)** | −2.1 (−7, 2.8) | 3.3 (−1.8, 8.5) | **−9.4 (−17, −1.8)** | **−10.7 (−18.3, −3.1)** | 2.8 (−2.3, 7.8) | **−1.0 (−1.3, −0.8)** | −0.4 (−0.8, 0) | 0.065 |

[1] Additional covariates of interest were added to the base model one at a time.

[2] Bold text indicates relationship with associated p<0.05.

[3] p values associated with the added covariate.

[4] Variables noted with ‘cent#’ were centered at the indicated value, thus allowing the intercept interpretation to be the estimated average value of after-work eGFR for a 40-year-old (at visit 1), female nursery worker in the summer of 2020 at the centered value of the additional covariate.

[5] V1 indicates ‘at visit 1, Winter 2020’.

[6] Family history of diabetes, hypertension, or kidney disease.

[7] Urine specific gravity >=1.020 both before and after work.

## TABLE 5.

Wintertime Predictors of Post-work eGFR Evaluated using Mixed Models with the Base Model containing Primary Work Type and Timepoint, Controlling for Sex and Age.

| MODEL[1] | Intercept | Primary Work Type | Winter21 | Sex | Age | Additional Covariate | |
|---|---|---|---|---|---|---|---|
| | | (ref=Nursery) | (ref=Winter20) | (ref=female) | (cent40)[4] | | |
| | Estimated Beta (95% confidence interval)[2] | | | | | | p-value[3] |
| **Base model** | 112.8 (107.9, 117.6) | 2 (−2.1, 6) | 2.3 (−1, 5.5) | 1.2 (−3.5, 6) | **−1.1 (−1.3, −0.8)** | | |
| **+ Health Factors** | | | | | | | |
| BMI (cent30)[4] | 112.8 (107.9, 117.8) | 1.9 (−2.2, 6) | 2.3 (−1, 5.5) | 1.2 (−3.6, 6) | **−1.1 (−1.4, −0.8)** | 0 (−0.4, 0.4) | 0.8951 |
| bp 120–139 or 80–89 (ref=<120/80) | 110.6 (105.2, 116.0) | 2.8 (−1.3, 6.9) | 1.2 (−2, 4.3) | 2.1 (−2.7, 6.9) | **−1.1 (−1.3, −0.8)** | 4.0 (−1.4, 9.5) | 0.1473 |
| bp140+ or 90+ (ref=<120/80) | | | | | | 2.2 (−2.1, 6.4) | 0.3201 |
| A1C >=5.7 at V1[5] | 112.1 (107.0, 117.2) | 2.4 (−1.8, 6.5) | 2.2 (−1.1, 5.5) | 1.4 (−3.4, 6.2) | **−1.1 (−1.4, −0.8)** | 2.6 (−2.7, 8) | 0.3334 |
| Resting heart rate | 108.9 (95.3, 122.4) | 2.0 (−2.1, 6) | 2.4 (−0.9, 5.6) | 1.0 (−3.9, 5.8) | **−1.1 (−1.3, −0.8)** | 0.1 (−0.1, 0.2) | 0.5426 |
| NSIAD use, sometimes/daily | 113.0 (108.1, 117.9) | 2.0 (−2.1, 6) | 2.4 (−0.9, 5.7) | 1.3 (−3.5, 6) | **−1.1 (−1.3, −0.8)** | −1.3 (−6.1, 3.4) | 0.5845 |
| Family hx kidney risk factors[6] | 111.1 (105.6, 116.6) | 2.1 (−2.1, 6.2) | 2.1 (−1.2, 5.4) | 1.3 (−3.7, 6.2) | **−1.1 (−1.4, −0.8)** | 3.1 (−0.9, 7.1) | 0.1296 |
| **+ Work Conditions** | | | | | | | |
| Training in HRI prevention | 111.8 (106.9, 116.8) | 1.7 (−2.3, 5.8) | 2.3 (−1, 5.5) | 1.1 (−3.6, 5.9) | **−1.1 (−1.4, −0.8)** | 3.4 (−0.8, 7.5) | 0.1118 |
| Pesticide use, years | 112.4 (107.0, 117.7) | 2.1 (−2, 6.2) | 2.3 (−1, 5.5) | 1.6 (−3.6, 6.8) | **−1.1 (−1.4, −0.8)** | 0.1 (−0.6, 0.8) | 0.723 |
| Workday duration | 111.9 (106.9, 116.8) | 3.2 (−1.1, 7.5) | 2.3 (−1, 5.5) | 1.5 (−3.3, 6.3) | **−1.1 (−1.3, −0.8)** | 0.9 (−0.2, 1.9) | 0.107 |
| Shade breaks taken | 112.1 (106.8, 117.3) | 2.1 (−1.9, 6.2) | 2.3 (−1, 5.5) | 1.1 (−3.7, 5.9) | **−1.1 (−1.4, −0.8)** | 1.3 (−2.4, 5.1) | 0.483 |
| Heat Index mean (cent90)[4] | 111.1 (103.8, 118.5) | 2.1 (−2, 6.2) | 1.8 (−1.7, 5.4) | 1.5 (−3.4, 6.3) | **−1.1 (−1.3, −0.8)** | −0.1 (−0.3, 0.1) | 0.5608 |
| HR mean at V1[5] (cent95)[4] | 112.6 (107.7, 117.6) | 2.1 (−2, 6.3) | 2.3 (−1, 5.5) | 1.3 (−3.5, 6.1) | **−1.1 (−1.4, −0.8)** | 0 (−0.3, 0.2) | 0.7682 |
| Workday Physical Activity mean at V1[5] | 110.9 (103.9, 118.0) | 0.9 (−4.2, 5.9) | 2.3 (−1, 5.5) | 1.6 (−3.3, 6.4) | **−1.1 (−1.3, −0.8)** | 13.8 (−24.9, 52.5) | 0.484 |
| HRI symptoms | 113.6 (108.5, 118.7) | 1.8 (−2.3, 5.8) | 1.9 (−1.4, 5.3) | 1.1 (−3.7, 5.9) | **−1.1 (−1.4, −0.8)** | −1.4 (−4.4, 1.6) | 0.3462 |
| **+ Hydration** | | | | | | | |
| Beverage consumption, oz. cent64[4] | 113 (108.1, 117.9) | 1.9 (−2.2, 5.9) | 2.2 (−1.1, 5.4) | 1.4 (−3.4, 6.3) | **−1.1 (−1.3, −0.8)** | 0 (0, 0.1) | 0.5398 |
| Sugary drinks consumption, oz | 111.4 (106.3, 116.5) | 2.7 (−1.7, 7.2) | 2.3 (−0.9, 5.5) | 1.8 (−3, 6.6) | **−1.1 (−1.3, −0.8)** | 0.1 (−0.1, 0.2) | 0.4541 |
| Dehydration both am & pm[7] | 113.7 (108.8, 118.7) | 2.5 (−1.5, 6.5) | 2.4 (−0.9, 5.7) | 0.6 (−4.2, 5.3) | **−1.1 (−1.4, −0.9)** | −4.1 (−9.5, 1.4) | 0.1417 |

| MODEL[1] | Intercept | Primary Work Type | Winter21 | Sex | Age | Additional Covariate | |
|---|---|---|---|---|---|---|---|
| | | (ref=Nursery) | (ref=Winter20) | (ref=female) | (cent40)[4] | | |
| | Estimated Beta (95% confidence interval)[2] | | | | | | p-value[3] |
| Serum Osmolality (cent295)[4] | 112.5 (107.9, 117.1) | 3.0 (−0.9, 6.8) | 0.9 (−2.4, 4.2) | −1.7 (−6.4, 3.1) | **−1.0 (−1.3, −0.8)** | **−1.0 (−1.5, −0.5)** | **0.0001** |

[1]Additional covariates of interest were added to the base model one at a time. A model with 'Heat Index, hrs >=100°F' was not calculated for winter data.

[2]Bold text indicates relationship with associated p<0.05.

[3]p values associated with the added covariate.

[4]Variables noted with 'cent#' were centered at the indicated value, thus allowing the intercept interpretation to be the estimated average value of after-work eGFR for a 40-year-old (at visit 1), female nursery worker in the summer of 2020 at the centered value of the additional covariate.

[5]V1 indicates 'at visit 1, Winter 2020'.

[6]Family history of diabetes, hypertension, or kidney disease.

[7]Urine specific gravity >=1.020 both before and after work.

## TABLE 6.

Summertime Predictors of Pre-work eGFR Evaluated using Mixed Models with the Base Model containing Primary Work Type and Timepoint, Controlling for Sex and Age.

| MODEL[1] | Intercept | Primary Work Type | Time | | Sex | Age | Additional Covariate | |
|---|---|---|---|---|---|---|---|---|
| | | (ref=Nursery) | Summer21 (ref=Summer20) | Summer22 (ref=Summer20) | (ref=female) | (cent40)[4] | | |
| | Estimated Beta (95% confidence interval)[2] | | | | | | | p-value[3] |
| **Base model** | **114.4 (111.1, 117.8)** | **3.6 (0.7, 6.5)** | −0.7 (−2.2, 0.8) | 0.8 (−0.7, 2.3) | **4.6 (1.3, 7.8)** | **−1.0 (−1.2, −0.9)** | | . |
| **+ Health Factors** | | | | | | | | |
| BMI cent30[4] | **114.4 (111.0, 117.7)** | **3.6 (0.7, 6.6)** | −0.7 (−2.2, 0.8) | 0.8 (−0.7, 2.3) | **4.6 (1.3, 7.8)** | **−1.0 (−1.2, −0.8)** | 0 (−0.3, 0.2) | 0.782 |
| BP 120–139 or 80–89 (ref=<120/80) | **115.5 (111.7, 119.2)** | **3.7 (0.8, 6.6)** | −0.8 (−2.3, 0.8) | 0.7 (−0.9, 2.2) | **5.0 (1.7, 8.2)** | **−1.0 (−1.2, −0.8)** | −1.6 (−4.3, 1.0) | 0.221 |
| BP140+ or 90+ (ref=<120/80) | | | | | | | −1.5 (−4.0, 1.0) | 0.242 |
| A1C >=5.7 at V1[5] | **114.0 (110.6, 117.5)** | **3.8 (0.9, 6.8)** | −0.7 (−2.2, 0.8) | 0.8 (−0.7, 2.3) | **4.6 (1.4, 7.8)** | **−1.0 (−1.2, −0.9)** | 1.4 (−2.3, 5.0) | 0.456 |
| Resting heart rate | **115.2 (111.9, 118.5)** | **3.5 (0.8, 6.3)** | −0.1 (−1.6, 1.3) | 1.8 (0.2, 3.4) | **3.8 (0.6, 7.0)** | **−1.0 (−1.2, −0.9)** | **0.1 (0.1, 0.2)** | **0.001** |
| NSAID use, sometimes or daily | **114.3 (111.0, 117.6)** | **3.5 (0.6, 6.4)** | −0.7 (−2.1, 0.8) | 0.8 (−0.7, 2.3) | **4.3 (1.1, 7.5)** | **−1.1 (−1.2, −0.9)** | **2.2 (0, 4.3)** | **0.049** |
| Family hx kidney risk factors[6] | **113.9 (110.2, 117.6)** | **3.6 (0.7, 6.5)** | −0.8 (−2.3, 0.7) | 0.6 (−0.9, 2.2) | **3.9 (0.7, 7.1)** | **−1.0 (−1.2, −0.8)** | 2.5 (−0.2, 5.1) | 0.069 |
| Urine specific gravity, pre-work, cent1.020[4] | **114.4 (111.0, 117.8)** | **3.5 (0.6, 6.5)** | −0.7 (−2.3, 0.8) | 0.7 (−0.9, 2.3) | **5.0 (1.8, 8.3)** | **−1.0 (−1.2, −0.8)** | 1.2 (0, 2.5) | 0.053 |
| **+ Work Conditions** | | | | | | | | |
| Training in HRI prevention | **114.0 (110.6, 117.4)** | **3.4 (0.6, 6.3)** | −0.7 (−2.2, 0.8) | 0.8 (−0.7, 2.3) | **4.5 (1.3, 7.7)** | **−1.1 (−1.2, −0.9)** | 1.5 (−1.4, 4.3) | 0.313 |
| Pesticide use, years | **116.2 (112.5, 119.8)** | **3.3 (0.4, 6.1)** | −0.7 (−2.2, 0.8) | 0.7 (−0.8, 2.3) | 3.0 (−0.5, 6.5) | **−1.0 (−1.2, −0.9)** | **−0.4 (−0.9, 0)** | **0.042** |

[1] Additional covariates of interest were added to the base model one at a time.

[2] Bold text indicates relationship with associated p<0.05.

[3] p values associated with the added covariate.

[4] Variables noted with 'cent#' were centered at the indicated value, thus allowing the intercept interpretation to be the estimated average value of after-work eGFR for a 40-year-old (at visit 1), female nursery worker in the summer of 2020 at the centered value of the additional covariate.

[5] V1 indicates 'at visit 1, Winter 2020'.

[6] Family history of diabetes, hypertension, or kidney disease.

**TABLE 7.**

Wintertime Predictors of Pre-work eGFR Evaluated using Mixed Models with the Base Model containing Primary Work Type and Timepoint, Controlling for Sex and Age.

| MODEL[1] | Intercept | Primary Work Type | Winter21 | Sex | Age | Additional Covariate | |
|---|---|---|---|---|---|---|---|
| | | (ref=Nursery) | (ref=Winter20) | (ref=female) | (cent40)[4] | | |
| Estimated Beta (95% confidence interval)[2] | | | | | | | p-value[3] |
| **Base model** | **117.8 (115, 120.6)** | **4.0 (1.4, 6.6)** | −0.3 (−1.7, 1.1) | 2.5 (−0.3, 5.2) | **−1.0 (−1.2, −0.8)** | | |
| **+ Health Factors** | | | | | | | |
| BMI cent30[4] | **118 (115.1, 120.8)** | **3.8 (1.2, 6.5)** | −0.3 (−1.7, 1.0) | 2.3 (−0.5, 5.1) | **−1.0 (−1.2, −0.8)** | 0.1 (−0.1, 0.3) | 0.390 |
| BP 120–139 or 80–89 (ref=<120/80) | **118 (114.8, 121.1)** | **3.8 (1, 6.6)** | −0.7 (−2.1, 0.7) | 2.6 (−0.2, 5.5) | **−1.0 (−1.2, −0.8)** | −1.1 (−3.5, 1.2) | 0.330 |
| BP140+ or 90+ (ref=<120/80) | | | | | | 0.7 (−2.1, 3.5) | 0.613 |
| A1C >=5.7 at V1[5] | **117.4 (114.5, 120.3)** | **4.2 (1.5, 6.8)** | −0.4 (−1.8, 1.0) | 2.5 (−0.2, 5.3) | **−1.0 (−1.2, −0.8)** | 1.7 (−1.5, 4.9) | 0.296 |
| Resting heart rate | **118 (115.1, 120.8)** | **4.0 (1.4, 6.6)** | −0.3 (−1.7, 1.1) | 2.2 (−0.6, 5.0) | **−1.0 (−1.1, −0.8)** | 0 (0, 0.1) | 0.312 |
| NSAID use, sometimes or daily | **117.8 (114.9, 120.6)** | **4.0 (1.4, 6.6)** | −0.4 (−1.8, 1.1) | 2.5 (−0.3, 5.2) | **−1.0 (−1.2, −0.8)** | 0.2 (−2.1, 2.5) | 0.847 |
| Family hx kidney risk factors[6] | **116.8 (113.7, 120)** | **3.9 (1.2, 6.5)** | −0.3 (−1.8, 1.1) | 2.1 (−0.7, 4.9) | **−1.0 (−1.2, −0.9)** | 2.3 (−0.1, 4.7) | 0.055 |
| Urine specific gravity, pre-work, cent1.020 | **117.5 (114.7, 120.4)** | **3.9 (1.3, 6.5)** | −0.5 (−2.0, 0.9) | **3.0 (0.2, 5.9)** | **−1.0 (−1.2, −0.8)** | 0 (−1.4, 1.5) | 0.949 |
| **+ Work Conditions** | | | | | | | |
| Training in HRI prevention | **118.1 (115.2, 121)** | **4.0 (1.4, 6.7)** | −0.3 (−1.7, 1.0) | 2.5 (−0.2, 5.2) | **−1.0 (−1.1, −0.8)** | −0.9 (−3.5, 1.6) | 0.468 |
| Pesticide use, years | **118.0 (114.9, 121.1)** | **3.9 (1.3, 6.6)** | −0.3 (−1.7, 1.1) | 2.3 (−0.7, 5.2) | **−1.0 (−1.2, −0.8)** | −0.1 (−0.5, 0.3) | 0.716 |

[1]Additional covariates of interest were added to the base model one at a time.

[2]Bold text indicates relationship with associated p<0.05.

[3]p values associated with the added covariate.

[4]Variables noted with 'cent#' were centered at the indicated value, thus allowing the intercept interpretation to be the estimated average value of after-work eGFR for a 40-year-old (at visit 1), female nursery worker in the summer of 2020 at the centered value of the additional covariate.

[5]V1 indicates 'at visit 1, Winter 2020'.

[6]Family history of diabetes, hypertension, or kidney disease.