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RESEARCH ARTICLE

Longitudinal and cross-sectional associations between the dietary inflammatory index and objectively and subjectively measured sleep among police officers

Michael D. Wirth[1,2,3] | Desta Fekedulegn[4] | Michael E. Andrew[4] | Alexander C. McLain[2] | James B. Burch[2,5,6] | Jean E. Davis[1] | James R. Hébert[2,3] | John M. Violanti[7]

[1]College of Nursing, University of South Carolina, Columbia, South Carolina, USA

[2]Department of Epidemiology and Biostatistics and Cancer Prevention and Control Program, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina, USA

[3]Department of Nutrition, Connecting Health Innovations, LLC, Columbia, South Carolina, USA

[4]Bioanalytics Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Morgantown, West Virginia, USA

[5]WJB Dorn VA Medical Center, Columbia, South Carolina, USA

[6]Department of Family Medicine and Population Health, School of Medicine, Virginia Commonwealth University, Richmond, Virginia, USA

[7]Department of Epidemiology and Environmental Health, School of Public Health and Health Professions, University at Buffalo, The State University of New York, Buffalo, New York, USA

Correspondence
Michael D. Wirth, MSPH, PhD, College of Nursing, University of South Carolina, 1601 Greene Street, Room 607, Columbia, SC 29208, USA.
Email: wirthm@email.sc.edu

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Summary

Police officers experience exposures associated with increased inflammation, such as the stress associated with shiftwork and poor-quality diet, both of which have been shown to affect sleep duration and quality. This study examined the longitudinal and cross-sectional effects of the Energy-density Dietary Inflammatory Index (E-DII™) on objectively and subjectively measured sleep among police officers. Data were derived from the Buffalo Cardio-Metabolic Occupational Police Stress Cohort (n = 464 at baseline), with longitudinal data collected from 2004 to 2019. A food frequency questionnaire obtained estimated dietary intake from which E-DII scores were calculated. Dependent variables were objectively (Micro Motion Logger Sleep Watch™) and subjectively (Pittsburgh Sleep Quality Index) measured sleep quality and quantity. The analyses included a series of linear mixed-effects models used to examine cross-sectional and longitudinal associations between the E-DII and sleep quantity and quality. Cross-sectionally, more pro-inflammatory diets were associated with higher wake-after-sleep-onset but improved subjective sleep quality. In models accounting for both longitudinal and cross-sectional effects, for every 1-unit increase in the E-DII scores over time (representing a pro-inflammatory change), wake-after-sleep-onset increased by nearly 1.4 min ($p = 0.07$). This result was driven by officers who primarily worked day shifts ($\beta = 3.33$, $p = 0.01$). Conversely, for every 1-unit increase in E-DII score, the Pittsburgh Sleep Quality Index global score improved. More pro-inflammatory diets were associated with increased wake-after-sleep-onset, an objective measure of sleep quality. Intervention studies to reduce dietary inflammatory potential may provide greater magnitude of effect for changes in sleep quality.

KEYWORDS
diet, inflammation, Pittsburgh Sleep Quality Index, shiftwork, sleep duration, sleep quality

1 | INTRODUCTION

Recommendations from the National Sleep Foundation indicate that adults aged 18+ years should receive at least 7 hr of sleep per night (Hirshkowitz et al., 2015). However, it is estimated that at least 30% of the US population sleeps less than 7 hr per night (Ford et al., 2015). About 33% of all adults experience symptoms of transient insomnia, 40% of whom develop more severe forms of insomnia (Pavlova & Latreille, 2019). In the general population, between 30% and 50% of men and between 11% and 23% of women report moderate-to-severe sleep apnea symptoms (Heinzer et al., 2015; Pavlova & Latreille, 2019). This is disconcerting given that adequate sleep is necessary for proper mental, emotional and physical restoration, and that poor sleep is associated with the development of numerous chronic conditions (Parish, 2009).

Pharmacological (e.g. benzodiazepines and non-benzodiazepine receptor agonists) interventions are among the most common treatments for sleep disorders (Brandt & Leong, 2017). However, such treatments can be habit-forming, and have been associated with a range of adverse effects including increased incidence of falls and fractures, dementia and other memory/cognition issues, infections, and mortality (Brandt & Leong, 2017). Excessive sleepiness and daytime fatigue are side-effects observed in more than 10% of those taking pharmacological treatments (Proctor & Bianchi, 2012).

Non-pharmacological approaches used to treat sleep ailments include mindfulness or cognitive behavioural therapy, melatonin supplementation, ear plugs/eye masks (i.e. sensory reduction), bright light therapy and exercise (Miller et al., 2019). Diet is an approach of particular importance. Adequate sleep duration (i.e. 7–8 hr per night) is associated with greater nutrient intake, and high-fat diets are associated with sleep disorders (Grandner et al., 2013; St-Onge et al., 2016). High-carbohydrate diets have been shown to decrease slow-wave sleep but increase rapid eye movement (REM; Afaghi et al., 2007; St-Onge et al., 2016).

Diets resembling a Western pattern (e.g. high in total and saturated fats, protein and added sugar) are more pro-inflammatory. Diets defined by high intake of fruits and vegetables, whole grains and fish (e.g. Mediterranean) are more anti-inflammatory (Ahluwalia et al., 2013). A sleep duration less than 7 hr or greater than 8 hr per night was associated with increased levels of pro-inflammatory cytokines in a meta-analysis of 72 studies (Irwin et al., 2016). Poor sleep quality or sleep disturbances and diagnosed sleep or sleep-related disorders such as insomnia or obstructive sleep apnea (OSA) also were found to be associated with inflammation (Irwin et al., 2016; Kapsimalis et al., 2008).

The Dietary Inflammatory Index (DII®) was designed to measure the pro- or anti-inflammatory nature of one's diet (Shivappa et al., 2014). The DII has been validated against inflammatory cytokines (Shivappa, Steck, Hurley, Hussey, Ma, et al., 2014; Wirth et al., 2014), and has been associated with inflammation-related outcomes such as cancer (Jayedi et al., 2018), diabetes (Denova-Gutierrez et al., 2018) and cardiovascular disease (Shivappa et al., 2018). More pro-inflammatory DII scores were associated with increased severity of OSA, daytime sleepiness and dysfunction, increased REM latency, short sleep duration (i.e. < 6 hr per night), and greater odds of reporting sleep disturbances or having "poor" sleep quality as defined by the Pittsburgh Sleep Quality Index (PSQI; Bazyar et al., 2021; Godos et al., 2019; Kase et al., 2020; Lopes et al., 2019; Masaad et al., 2020). Using data from an anti-inflammatory diet intervention, Wirth and colleagues found that individuals in the first tertile for the change in DII scores (i.e. anti-inflammatory diet changes) compared with individuals in the third tertile (i.e. pro-inflammatory diet changes) had a reduction of nearly 25 min of wake-after-sleep-onset (WASO), and about a 2.6% increase in sleep efficiency (Wirth et al., 2020).

Shiftwork has long been associated with circadian disruption and sleep disturbances (Moreno et al., 2019). In addition to this, night and rotating shift-workers have higher levels of inflammation compared with their day shift-working counterparts (Puttonen et al., 2011). In terms of diet, findings from a meta-analysis demonstrated that total energy intake does not differ between day and night shift workers; however, diet quality is poorer among those who work nights (Bonham et al., 2016). Correspondingly, night and rotating shift-workers tend to have more pro-inflammatory diets than primarily day shift workers (Wirth et al., 2014, 2017). Police officers are frequently exposed to shiftwork, increased stress and other environmental situations that may predispose them to experiencing poor sleep, increased inflammation or poor access to healthy food options (Garbarino et al., 2019; Wirth et al., 2013).

The Buffalo Cardio-Metabolic Occupational Police Stress (BCOPS) cohort study was designed to examine biological processes through which stressors of police work influence adverse health outcomes (Violanti et al., 2006). Using data from BCOPS, this study tested the hypothesis that more pro-inflammatory diets would be associated with shorter sleep duration and poorer sleep quality, measured both objectively and subjectively, compared with those with more anti-inflammatory diets. Additionally, shiftwork experience was examined as an effect modifier.

2 | METHODS

2.1 | Study population

Active-duty police officers were recruited to participate in the BCOPS study cohort, with baseline visits occurring between 2004 and 2009 ($n = 464$), first follow-up between 2011 and 2015 ($n = 281$), and second follow-up between 2015 and 2019 ($n = 240$). Assessments occurred in the morning of a training day during standard daytime work hours or on a day shift. The protocol for the BCOPS study included the collection for stress biomarkers, psychosocial factors, behaviour (e.g. diet, sleep, physical activity), shiftwork and markers of adverse health outcomes (e.g. subclinical cardiovascular disease; Violanti et al., 2006). The BCOPS study received Institutional Review Board approval from the National Institute of Occupational Safety and Health and The State University of New York at Buffalo. All officers provided written informed consent.

2.2 | Diet assessment and computation of the DII

A food frequency questionnaire (FFQ) was used to determine amount and frequency of consumption of 144 different foods and beverages from which micro- and macronutrients were derived. Development and initial validation of the DII have been described elsewhere (Shivappa, Steck, Hurley, Hussey, & Hebert, 2014; Shivappa, Steck, Hurley, Hussey, Ma, et al., 2014). Various DII food parameters were assigned an article effect score based on past research examining a specific food parameter's impact on systemic inflammation. Police officers' diets were compared with a global database containing means and standard deviations from 11 populations around the world. *Z*-scores were created by subtracting the global mean from reported intake and then dividing by the global standard deviation. These were then converted to proportions, and centred on 0 by doubling and subtracting 1. Next, they were then multiplied by the article effect score for each DII food parameter and summed to get the overall DII score. To account for individual differences in energy intake, an energy-density approach (Energy-density DII or E-DII) was taken to specifically calculate DII scores per 1000 kilocalories (kcals) consumed. The E-DII food parameters available for BCOPS included: carbohydrates; protein; fat; alcohol; fibre; cholesterol; saturated, monounsaturated and polyunsaturated fat; omega 3 and 6 fatty acids; trans-fat; niacin; thiamin; riboflavin; vitamins B12, B6, A, C, D and E; iron; magnesium; zinc; selenium; folic acid; beta carotene; isoflavones; and caffeine.

2.3 | Characterization of sleep

Sleep duration and quality were objectively measured using the Micro Motion Logger Sleep Watch™ (Ambulatory Monitoring, NY, USA). Police officers wore the device on their non-dominant wrist for 15 consecutive days. All sleep characterization was conducted using Action-W software (Ambulatory Monitoring, NY, USA) using the Cole–Kripke algorithm for sleep scoring. Fifteen-day average sleep outcomes included time in bed (TIB; time from lying down to getting out of bed indicated by pressing a button on the device), total sleep duration excluding naps, sleep efficiency (percentage of time spent asleep during TIB), WASO (time spent awake after first persistent sleep of at least 20 min), sleep latency (time between lying down and sleep onset), and a sleep fragmentation index (ratio of number of awakenings to total sleep time during TIB), which is a measure of restlessness (Fekedulegn et al., 2020).

Subjective sleep quality was assessed using the PSQI (Buysse et al., 1989). This self-administered survey contains 19 questions with seven component scores, and a global score ranging from 0 to 21 with higher scores indicating worse sleep quality. For the global score, a cut-off point of 5.0 (i.e. good sleepers versus poor sleepers) has been shown to have a sensitivity of 90% and a specificity of 87% in identifying those with a sleep disorder (Buysse et al., 1989).

2.4 | Shiftwork derivation and covariates

The Buffalo, New York Police Department provided access to electronic payroll records for shiftwork characterization. Using payroll records from 1994 or date of employment, officers were categorized into day/morning shift, evening shift and night shift based on the shift with the largest percentage of work hours. It was observed that for 85% of officers, at least 70% of their work hours were spent primarily in one shift type. For 99% of records, work start times were consistent with the following start times: 07:00 hours or 08:00 hours (for day shift); 16:00 hours (for evening shift); and 20:00 hours or 21:00 hours (for night shift). For the remaining 1% of shifts, the following start time ranges were used for categorization: day shift (start times between 04:00 hours and 11:59 hours); evening shift (between 12:00 hours and 19:59 hours); and night shift (between 20:00 hours and 03:59 hours). Long-term shift assignment (i.e. day, afternoon or night) was used in this analysis, as well as average percentage of hours spent on the day shift per week (as a continuous metric).

Factors determined to be confounders in at least one of the models presented in the Results included demographics (i.e. age, race, education and sex); behavioural information (i.e. sleep medication usage based on the PSQI, tobacco use and alcohol consumption); work history (i.e. average percentage of weekly hours spent on the day shift, years employed as a police officer, number of cumulative shift changes, and rank); clinical measures (i.e. body mass index [BMI, kg m^{-2}] calculated through measured height and weight, waist circumference, and systolic blood pressure); and psychosocial metrics. The psychosocial measures included the Center for Epidemiologic Studies Depression (CES-D) scale, Beck Anxiety Inventory (BAI), and the Impact of Events (IES). Further operational definitions of these confounders can be located in Table 1.

2.5 | Statistical analyses

Baseline population characteristics were described according to the entire population, as well as by categories of the independent variable: E-DII (< −3.0 [very anti-inflammatory], −3.0 to −1.01 [moderately anti-inflammatory], −1 to 0.99 [neutral], ≥ 1.0 [pro-inflammatory]). Moderately pro-inflammatory (1.0–3.0) and very pro-inflammatory (> 3.0) were combined given a small sample size within very pro-inflammatory. Chi-square tests and ANOVAs were used to compare population characteristics across E-DII categories.

The dependent variables of interest included TIB, sleep duration minus naps, sleep efficiency, WASO, sleep latency, an index of sleep fragmentation, and the global PSQI score. All were treated as continuous metrics. The independent variable of interest was the E-DII treated as both continuous and categorical in separate models. A mixed model with a random intercept with both dependent and independent variables varying over time estimated the impact of E-DII on sleep at any given time point, and is referred to as the stationary model. Next, models allowing for the differential impacts of baseline E-DII (i.e. cross-sectional) and E-DII change from baseline (i.e. longitudinal [β_{change}]) on

TABLE 1 Baseline sample characteristics overall and by E-DII categories among the BCOPS cohort

Characteristic	All	E-DII category I ($n = 71$)	E-DII category II ($n = 109$)	E-DII category III ($n = 121$)	E-DII category IV ($n = 100$)	p-Value
Sex						<0.01
Male	295 (74%)	43 (61%)	68 (62%)	99 (82%)	85 (85%)	
Female	106 (26%)	28 (39%)	41 (38%)	22 (18%)	15 (15%)	
Race						0.14
European–American	303 (77%)	51 (72%)	78 (73%)	100 (84%)	74 (76%)	
Other	91 (23%)	20 (28%)	29 (27%)	19 (16%)	23 (24%)	
Education						0.47
Less than college degree	184 (46%)	33 (46%)	45 (41%)	54 (45%)	52 (52%)	
Associates degree	85 (21%)	18 (25%)	28 (26%)	24 (20%)	15 (15%)	
Bachelors or graduate degree	132 (33%)	20 (28%)	36 (33%)	43 (36%)	33 (33%)	
Rank						0.88
Police officer	280 (70%)	47 (66%)	76 (70%)	89 (74%)	68 (68%)	
Sergeant, lieutenant or captain	67 (17%)	15 (21%)	17 (19%)	16 (13%)	17 (17%)	
Detective/other	54 (13%)	9 (13%)	14 (13%)	16 (13%)	15 (15%)	
Primary shift worked						0.27
Day	165 (42%)	37 (53%)	47 (44%)	45 (38%)	36 (36%)	
Evening	136 (34%)	18 (26%)	36 (34%)	41 (34%)	41 (41%)	
Night	96 (24%)	15 (21%)	24 (22%)	34 (28%)	23 (23%)	
Sleep medicine use						0.73
Not during past month	320 (82%)	55 (79%)	86 (81%)	100 (83%)	79 (85%)	
At least once past month	69 (18%)	15 (21%)	20 (19%)	20 (17%)	14 (15%)	
Tobacco use						0.05
Never	206 (52%)	37 (54%)	52 (49%)	60 (50%)	57 (58%)	
Former	85 (22%)	21 (30%)	28 (26%)	23 (19%)	13 (13%)	
Current	104 (26%)	11 (16%)	26 (24%)	38 (31%)	29 (29%)	
Age (years)[a]	41.5 ± 6.7	42.5 ± 6.7	41.4 ± 6.5	41.2 ± 6.9	41.3 ± 6.9	0.28
BMI (kg m^{-2})[a]	29.3 ± 4.8	28.4 ± 4.4	28.7 ± 4.5	30.1 ± 5.1	29.5 ± 4.7	0.14
Waist circumference (cm)[a]	94.5 ± 14.3	89.8 ± 12.4	91.9 ± 14.5	97.6 ± 14.4	97.0 ± 14.0	<0.01
Day shift hours per week (Average %)[a]	11.9 ± 10.6	14.4 ± 10.7	12.5 ± 10.5	10.1 ± 10.5	11.8 ± 10.7	0.12
Years employed as police officer[a]	15.0 ± 7.2	15.6 ± 7.3	14.4 ± 6.96	15.0 ± 6.7	15.3 ± 8.0	0.80
Systolic blood pressure (mmHg)[a]	121 ± 12	118 ± 12	121 ± 12	121 ± 12	123 ± 13	0.02
Alcoholic drinks per week[b]	2.8 (0.4–6.3)	1.9 (0.4–4.3)	2.8 (0.4–5.3)	4.0 (0.6–8.7)	2.3 (0.5–5.9)	0.08
Cumulative total shift changes[b]	24 (12–44)	19 (11–40)	22 (11–45)	26 (12–46)	29 (15–48.5)	0.35
CES-D scale[b]	6 (3–10.5)	4.5 (2–8)	5 (3–10)	7.5 (3–11)	7 (4–13)	0.06
IES scale[b]	8 (2–17)	7 (3–13)	7 (1–15)	9 (2–20)	10 (3–17)	0.22
BAI[b]	4 (1–9)	4 (0–8)	4 (1–7)	5 (1–10)	5 (2–10)	0.15

Frequencies within E-DII categories may not equal column totals due to missing data. Column percentages may not equal 100% due to rounding. For categorical covariates frequencies (percentages) were presented and p-values were obtained using chi-square tests. DII range for the categories were as follows: (I) Very Anti-inflammatory = ≤−3.0; (II) Moderately Anti-inflammatory = −2.99 to −1.0; (III) Neutral = −1 to 0.99; and (IV) Pro-inflammatory ≥ 1.0.

BAI, Beck Anxiety Inventory; BCOPS, Buffalo Cardio-Metabolic Occupational Police Stress; BMI, body mass index; CES-D, Center for Epidemiologic Study Depression; E-DII, Energy-density Dietary Inflammatory Index; IES, Impact of Events.

[a] For normally distributed continuous covariates, means ± standard deviations were presented, and p-values representing the comparison between DII density categories I and IV were obtained using one-way ANOVAs.

[b] For non-normal continuous covariates, medians (interquartile range) were presented, and p-values were obtained using Kruskal–Wallis tests.

The CES-D scale had a maximum range of 0–60, with higher scores indicating more depressive symptoms. The Impact of Events scale had a maximum range of 0–88, with higher values indicating more distress from traumatic events. The BAI had a maximum range of 0–63, with higher values indicating greater anxiety.

TABLE 2 Associations between the DII and sleep quantity and quality

Sleep metric	Very Anti-inflammatory	Moderately Anti-inflammatory	Neutral	Pro-inflammatory	*p*-Value: very anti vs. pro	DII continuous beta (*SE*)	*p*-Value continuous
TIB (hr)	7.38 (7.19–7.58)	7.24 (7.07–7.41)	7.31 (7.12–7.49)	7.51 (7.28–7.73)	0.37	0.007 (0.020)	0.72
Night sleep duration (hr)	6.43 (6.21–6.65)	6.30 (6.11–6.50)	6.23 (6.02–6.44)	6.35 (6.09–6.60)	0.57	−0.028 (0.023)	0.21
Sleep efficiency (%)	86.5 (84.8–88.1)	86.5 (85.1–88.0)	85.0 (83.5–86.4)	85.3 (83.4–87.1)	0.31	−0.277 (0.176)	0.12
WASO (min)	41.8 (36.9–46.7)	39.9 (35.8–43.9)	46.0 (41.9–50.0)	47.6 (42.0–53.2)	0.12	1.284 (0.555)	0.02
Sleep latency (min)	4.58 (3.74–5.42)	4.66 (3.92–5.39)	4.69 (3.88–5.50)	4.20 (3.19–5.20)	0.52	−0.054 (0.089)	0.55
Sleep fragmentation	3.74 (3.39–4.09)	3.71 (3.39–4.02)	3.99 (3.67–4.30)	4.03 (3.63–4.43)	0.24	0.066 (0.037)	0.08
PSQI global sleep score	7.35 (6.85–7.85)	7.18 (6.77–7.60)	6.59 (6.17–7.01)	6.61 (6.08–7.13)	0.04	−0.141 (0.055)	0.01

p-Value Very Anti versus Pro represents the *p*-value for the least square difference in outcomes between the Very Anti-Inflammatory group and the Pro-inflammatory group. DII Continuous Beta represents the beta coefficient for the continuous form of the DII. *p*-Value Continuous represents the *p*-value for the continuous form of the DII. The DII was allowed to vary with time. The DII ranges for the categories were as follows: Very Anti-inflammatory = ≤−3.0; Moderately Anti-inflammatory = −2.99 to −1.0; Neutral = −1 to 0.99; and Pro-inflammatory ≥ 1.0. Adjustments: TIB – race, education, sex, sleep medications, average day shift hours per week, and CES-D; Night Sleep Duration – race, sex, sleep medication, BMI, systolic blood pressure, average day shift hours per week and CES-D; Sleep Efficiency – race, tobacco use, BMI, systolic blood pressure, years of employment as a police officer, and average day shift hours per week; WASO – tobacco use, BMI, systolic blood pressure, years of employment as a police officer, waist circumference, average number of alcoholic drinks per week, and average day shift hours per week; Sleep Latency – sex, rank, years of employment as a police officer, waist circumference, and BAI; Sleep Fragmentation – race, tobacco use, BMI, systolic blood pressure, and average day shift hours per week; Global PSQI Score - years of employment as a police officer, CES-D, IES and BAI.

BMI, body mass index; CES-D, Center for Epidemiologic Studies Depression Scale; DII, Dietary Inflammatory Index; PSQI, Pittsburgh Sleep Quality Index; *SE*, standard error; TIB, time in bed; WASO, wake-after-sleep-onset.

sleep were conducted. Model selection for both models started as a series of bivariate analyses (i.e. dependent = E-DII + covariate). If the covariate had a *p*-value of ≤ 0.15, it was included in a full model. The final model was achieved by a backward removal process. If the beta coefficient of the E-DII changed substantially (e.g. ± 10% or more), the covariate was put back into the model; otherwise, it remained out. Statistically significant covariates also remained in the model. Model residuals were examined for their adherence to the assumptions of linear regression; no violations were found. The categorical E-DII also was used to obtain least square means of the dependent variables in the stationary effect models. For the differential model, a contrast statement was included to compare the cross-sectional and longitudinal effects. Only the continuous E-DII was used in the differential analyses as interpreting changes in DII category assignment over time may become highly nuanced. Lastly, shiftwork was examined as a potential effect modifier by examining the interaction between the change in DII and the categorical long-term shift assignment (i.e. day, evening or night shift) in the differential effects model.

3 | RESULTS

Participants were mainly male (74%), European–American (77%), held a rank of police officer (70%) as compared with higher level positions, and were less than college educated or had an associate degree only (67%) at baseline. The average age was 41.5 ± 6.7 years, average BMI was 29.3 ± 4.8 kg m^{-2}, and the average years employed as a police officer was 15.0 ± 7.2 years (Table 1) at baseline. The average E-DII was −0.67 ± 2.16, which indicates a neutral inflammatory diet. When comparing sample characteristics by E-DII category, those with more pro-inflammatory diets compared with more anti-inflammatory diets were more likely to be male ($p < 0.01$), to be current smokers ($p = 0.05$), have a higher waist circumference ($p < 0.01$), and have higher systolic blood pressure ($p = 0.02$) at baseline (Table 1).

In the stationary effect models, every 1-unit increase (i.e. more pro-inflammatory) in the E-DII score was associated with an adjusted higher WASO of 1.28 min ($SE = 0.56$, $p = 0.02$). No other differences were observed for objective measures either when using the E-DII in its continuous or categorical form. Every 1-unit increase in the E-DII was associated with a −0.14 ($SE = 0.06$, $p = 0.01$) decrease (i.e. improvement) in the PSQI global sleep score. Categorically, those in the pro-inflammatory E-DII category had a lower mean PSQI than the very anti-inflammatory category (6.61 versus 7.35, $p = 0.04$; Table 2).

For the analytical approach that examined the differential impact of cross-sectional and longitudinal effects within the same model, every 1-unit increase in the change in E-DII score (i.e. becoming more pro-inflammatory over time), WASO increased by 1.36 min ($SE = 0.74$, $p = 0.07$) and the global PSQI sleep score improved ($\beta_{change} = -0.22$, $SE = 0.01$, $p < 0.01$). No other statistically significant results were observed among the full sample (Table 3). However, notable interactions (i.e. $p < 0.20$) were observed between the change in E-DII and shift status for sleep efficiency ($p = 0.06$), sleep latency ($p = 0.15$), WASO ($p = 0.18$) and sleep fragmentation

TABLE 3 Longitudinal changes and baseline effects of the DII on various sleep parameters

Sleep metric	β_{Change} (*SE*)	*p*-Value β_{Change}	β_{Base} (*SE*)	*p*-Value β_{Base}	*p*-Value β_{Change} versus β_{Base}
TIB (hr)	−0.00 (0.03)	0.91	0.01 (0.02)	0.56	0.57
Night sleep duration (hr)	−0.03 (0.03)	0.34	−0.04 (0.03)	0.19	0.84
Sleep efficiency (%)	−0.16 (0.34)	0.23	−0.32 (0.21)	0.12	0.52
WASO (min)	1.36 (0.74)	0.07	1.14 (0.66)	0.08	0.54
Sleep latency (min)	−0.18 (0.13)	0.16	−0.02 (0.09)	0.83	0.21
Sleep fragmentation	0.03 (0.05)	0.54	0.08 (0.04)	0.06	0.35
PSQI global sleep score	−0.22 (0.07)	<0.01	−0.08 (0.07)	0.22	0.11

p-Value β_{Change} represents the *p*-value for the longitudinal change in DII score beta coefficient. *p*-Value β_{Base} represents the *p*-value for the baseline DII beta coefficient. *p*-value β_{Change} versus β_{Base} represents the *p*-value for the contrast between β_{Base} and β_{Change}. The change in DII was defined as the baseline DII minus the value at later time points. Adjustments: TIB – race, education, sex, sleep medications, average day shift hours per week, and CES-D; Night Sleep Duration – race, sleep medication, BMI, systolic blood pressure, average day shift hours per week, and CES-D; Sleep Efficiency – race, tobacco use, BMI, systolic blood pressure, years of employment as a police officer, number of career cumulative shift changes, average day shift hours per week; WASO – tobacco use, BMI, systolic blood pressure, years of employment as a police officer, waist circumference, average number of alcoholic drinks per week, number of career cumulative shift changes, and average day shift hours per week; Sleep Latency – rank, BMI, years of employment as a police officer, average day shift hours per week; Sleep Fragmentation – race, tobacco use, BMI, systolic blood pressure, number of career cumulative shift changes, and average day shift hours per week; Global PSQI Score – years of employment as a police officer, CES-D, IES and BAI.

BMI, body mass index; CES-D, Center for Epidemiologic Studies Depression Scale; DII, Dietary Inflammatory Index; PSQI, Pittsburgh Sleep Quality Index; *SE*, standard error; TIB, time in bed; WASO, wake-after-sleep-onset.

TABLE 4 Effect of longitudinal changes in the DII on various sleep parameters stratified by long-term shift type

	Day shift		Evening shift		Night shift	
Sleep metric	β_{Change} (*SE*)	*p*-Value	β_{Change} (*SE*)	*p*-Value	β_{Change} (*SE*)	*p*-Value
TIB (hr)	−0.02 (0.15)	0.69	0.00 (0.03)	0.99	−0.03 (0.06)	0.59
Night sleep duration (hr)	−0.06 (0.05)	0.28	0.02 (0.04)	0.69	0.06 (0.07)	0.44
Sleep efficiency (%)	−0.69 (0.40)	0.08	0.00 (0.37)	0.99	1.07 (0.52)	0.04
WASO (min)	3.27 (1.24)	0.01	1.06 (1.11)	0.34	−1.00 (1.70)	0.56
Sleep latency (min)	−0.04 (0.19)	0.81	−0.18 (0.23)	0.43	−0.71 (0.21)	<0.01
Sleep fragmentation	0.16 (0.08)	0.07	0.04 (0.07)	0.57	−0.09 (0.12)	0.44
PSQI global sleep score	−0.24 (0.14)	0.08	−0.19 (0.11)	0.07	−0.28 (0.17)	0.10

The change in DII was defined as the baseline DII minus the value at later time points. Adjustments: TIB – race, education, sex, sleep medications, average day shift hours per week, and CES-D; Night Sleep Duration – race, sleep medication, BMI, systolic blood pressure, average day shift hours per week, and CES-D; Sleep Efficiency – race, tobacco use, BMI, systolic blood pressure, years of employment as a police officer, number of career cumulative shift changes, average day shift hours per week; WASO – tobacco use, BMI, systolic blood pressure, years of employment as a police officer, waist circumference, average number of alcoholic drinks per week, number of career cumulative shift changes, and average day shift hours per week; Sleep Latency – rank, BMI, years of employment as a police officer, average day shift hours per week; Sleep Fragmentation – race, tobacco use, BMI, systolic blood pressure, number of career cumulative shift changes, and average day shift hours per week; Global PSQI Score - years of employment as a police officer, CES-D, IES and BAI.

BMI, body mass index; CES-D, Center for Epidemiologic Studies Depression Scale; DII, Dietary Inflammatory Index; PSQI, Pittsburgh Sleep Quality Index; *SE*, standard error; TIB, time in bed; WASO, wake-after-sleep-onset.

($p = 0.14$) models (Table 4). Sleep latency appeared to decrease among the night shift group with increasing pro-inflammatory diets ($\beta_{change} = -0.71$, $SE = 0.21$, $p < 0.01$); whereas, no such relationship was observed among day or evening shift-workers. Among day shift officers, but not evening or night shift officers, every 1-unit increase in the change in E-DII was associated with a 3.33-min ($SE = 1.24$, $p = 0.01$) increase in WASO. A 1-unit increase in the change in E-DII score was associated with an improvement in sleep efficiency in night shift officers, but a worsening in sleep efficiency among day-shift officers (Table 4).

4 | DISCUSSION

In this population of police officers, an occupational group exposed to numerous stressors that can affect sleep (Wirth et al., 2013), every 1-unit increase in the change in E-DII over time (i.e. becoming more pro-inflammatory over time) increased WASO by 3.33 min in officers primarily working day shifts. Similarly, post hoc analyses of a self-selection DII-based clinical trial (the Inflammation Management Intervention or IMAGINE) found similar results (Wirth et al., 2020). For that analysis, participants in the control and intervention arms were combined due to high rates of crossover between study arms. Within IMAGINE, those with the most anti-inflammatory dietary changes over 3 months decreased WASO by 25 min per night, whereas no change was observed in participants with pro-inflammatory E-DII changes ($p < 0.01$; Wirth et al., 2020).

Among United Arab Emirates college students, mean E-DII scores were greater (0.55 versus 0.07, respectively, $p = 0.01$) among those with PSQI-based daytime dysfunction compared with those without daytime dysfunction (Masaad et al., 2020) and, among Iranian female college students, every 1-unit increase in the E-DII score was associated with greater odds (odds ration [OR] = 1.22, 95% confidence interval [CI] = 1.03–1.44) of poor sleep according to the PSQI (Bazyar et al., 2021). In a cross-sectional study among those with OSA from Brazil, the E-DII was found to be a predictor of sleep apnea severity and daytime dysfunction (as measured by the PSQI) among older adults (Lopes et al., 2019). Also using the PSQI, Godos and colleagues found that Italian adults with the most pro-inflammatory diets, compared with anti-inflammatory diets, had lower odds of having "good" sleep quality (OR = 0.49, 95% CI = 0.31–0.78; Godos et al., 2019). Using data from the National Health and Nutrition Examination Survey from the USA, Kase and colleagues found that the most pro-inflammatory E-DII group, compared with the most anti-inflammatory group, had elevated odds of ≤ 6 hr of sleep per night (OR = 1.40, 95% CI = 1.21–1.61), ≥ 9 hr of sleep per night (OR = 1.23, 95% CI = 1.03–1.46), and self-reported sleep disturbances (OR = 1.14, 95% CI = 1.02–1.27; Kase et al., 2020).

Of the past studies described above, five were cross-sectional (Bazyar et al., 2021; Godos et al., 2019; Kase et al., 2020; Lopes et al., 2019; Masaad et al., 2020), four were international studies with two of those focusing on college students and one on adults with OSA (Bazyar et al., 2021; Godos et al., 2019; Lopes et al., 2019; Masaad et al., 2020), and four included only self-report measures of sleep (Bazyar et al., 2021; Godos et al., 2019; Kase et al., 2020; Masaad et al., 2020). The Brazilian study used polysomnography (PSG), the most rigorous sleep assessment (Lopes et al., 2019). The IMAGINE study was the most comparable to the current study in terms of the longitudinal design and sleep measurement devices (Wirth et al., 2020). A recent review provides further support related to associations between dietary index scores and sleep quality; specifically, healthy diets being associated with better sleep quality (Godos et al., 2021). However, the authors of that review further stated that the evidence is limited given most studies were cross-sectional in nature and that most sleep assessments were subjective (Godos et al., 2021). The current study made use of a longitudinal design and objective markers of sleep.

Interestingly, statistically significant findings were in the opposite direction for sleep latency and sleep efficiency than hypothesized for those working primarily night shifts. However, fatigue may actually be associated with a decreased sleep latency in populations experiencing elevated fatigue (e.g. those undergoing cancer treatment; Holliday et al., 2016). Study design phenomena may also explain these findings. In a longitudinal study, individuals who struggle with the adverse effects of night work (e.g. sleep disturbances) may leave the occupation or switch to another shift type. This may create a selection bias where those who continue to work the night shift may be healthier in certain domains compared with their day-working counterparts, or those no longer working in the profession. This is partly evidenced by the fact that over the full study from baseline to the second follow-up, day shift membership decreased by 22%, evening shift by 48% and night shift by 53%. Within those that remained in the night shift category, some officers may inherently be better able to deal with the adverse effects of shiftwork either through long years of training or genetics (Burch et al., 2009). This enhanced coping may lead to fewer adverse effects of shiftwork on sleep. At the same time, it is possible that some officers may be able to consume high-fat/high-sugar foods without it adversely impacting sleep as much as in other officers working the night shift. This may create a phenomenon where a subset of night shift officers has better sleep quality but more pro-inflammatory diets, which may explain results that were opposite to the hypothesized effect in night shift workers.

In the current study, more pro-inflammatory diets were associated with better subjective sleep quality. Kline and colleagues observed that actigraphically measured total sleep time was, on average, about 1.25 hr less than subjectively reported total sleep time. Subjective total sleep time more closely resembled TIB from actigraphy (Kline et al., 2010). It also is possible that reporting bias related to social desirability or the desire to make oneself feel better about their own health or lifestyle habits impacted self-reporting.

The average E-DII scores of the police officers in this study fell into the neutral category at baseline. This is consistent with shift-workers in the general American population (Wirth et al., 2017). Biologically, it is possible that the E-DII is associated with various aspects of sleep. For example, sleep-promoting cytokines include tumour necrosis factor (TNF)-α and interleukin (IL)-1β, both of which are pro-inflammatory. IL-1β can stimulate growth-hormone-releasing hormone, which enhances non-REM sleep (Obal & Krueger, 2003). IL-6 may be involved with sleep initiation as it peaks around the time of sleep onset. Additionally, administration of high levels of IL-6 can disrupt sleep structure (Kapsimalis et al., 2008). Chronic exposure to poor diets may, in a similar manner, disrupt the rhythm of IL-6 secretion leading to similar effects as seen with administration of high levels of IL-6.

The E-DII score includes a range of dietary components that impact bodily processes other than inflammation, some of which may impact sleep. High-fat diets can decrease sleep efficiency; whereas, high-carbohydrate diets may improve sleep structure (St-Onge et al., 2016). Supporting this potential mechanism is the fact that those in the very anti-inflammatory group (at baseline) consumed 29% of total energy intake as fat versus 39% ($p < 0.01$) in those in the pro-inflammatory group (data not shown). Carbohydrate consumption may increase tryptophan availability for later synthesis of serotonin and melatonin, which may facilitate sleep (Doherty et al., 2019).

Compared with other research in this field, a longitudinal design and an analysis that differentiated between cross-sectional and longitudinal effects were study strengths. Objective measures of sleep were assessed. The E-DII very specifically focuses on dietary inflammation, which is important given the inflammatory underpinnings of sleep. A range of covariates, including stress, were evaluated as potential confounders.

However, limitations should be considered when interpreting the results. The population was primarily European–American males, which may limit generalizability. Dietary data were obtained through self-report using a FFQ. Additionally, there was considerable attrition across time points, and this attrition may have been due to biases related to selective work adaptation abilities or a healthy worker effect. Lastly, work and off days were not separated in the actigraphy measures, and it is conceivable that sleep and diet are different on work versus off days.

Among day workers, a more pro-inflammatory diet change over time was associated with increased time spent awake after initially falling asleep. Specifically, if these individuals could make their E-DII score more anti-inflammatory by 5 points, then the results indicate they may decrease time spent awake by about 17 min per night (119 min per week). This nearly 2-hr increase in sleep per week could help to alleviate sleep debt. The concern of sleep debt is particularly important for police officers, as research has indicated that sleep is associated with stress, metabolic abnormalities, poor mental health and other adverse health outcomes among police officers (Garbarino et al., 2019; Garbarino & Magnavita, 2019). Future studies should employ more rigorous sleep assessments, such as PSG, to more thoroughly investigate mechanisms of action between dietary inflammation and sleep. This is important given there is a bidirectional relationship between sleep and inflammation, and that sleep may impact dietary choices (Vidafar et al., 2020). Understanding if these results apply to other working populations such as nurses could potentially extend these findings to a larger segment of the population.

CONFLICT OF INTEREST

Dr James Hébert owns a controlling interest in Connecting Health Innovations LLC (CHI), a company licensing the right to his invention of the Dietary Inflammatory Index (DII®) from the University of South Carolina in order to develop computer and smart phone applications for patient counseling and dietary intervention in clinical settings. In addition to their University of South Carolina appointments, Dr Michael Wirth was an employee of CHI. The findings and conclusions in this report are those of the author(s), and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

AUTHOR CONTRIBUTIONS

M.D.W. led the drafting of the manuscript. All other co-authors contributed to writing and careful review of complete drafts. D.F., M.E.A., J.B.B. and J.M.V. were involved in data collection. Statistical analyses were led by M.D.W., with A.C.M. and D.F. providing statistical support. M.D.W. and J.R.H. were responsible for development of the Dietary Inflammatory Index. J.E.D. provided expert review and interpretation of objective sleep metrics.

DATA AVAILABILITY STATEMENT

The data underlying this article were provided by NIOSH under license/by permission.

ORCID

Michael D. Wirth https://orcid.org/0000-0001-7610-8008
Desta Fekedulegn https://orcid.org/0000-0002-1820-4373

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