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RESEARCH ARTICLE

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Diurnal cortisol patterns in chronic pain: Associations with work-family spillover, work, and home stress

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ABSTRACT

Chronic pain is a prevalent condition with significant impacts on individuals' lives, including heightened stress and impaired physiological functioning. Given that work and family are the two main social domains where stress manifests, this study aimed to investigate the interactions between chronic pain, work-family stressors, and diurnal cortisol patterns to understand how chronic pain affects daily life and physiological stress responses. We identified 1,413 adults with chronic pain and 1,413 matched controls within MIDUS II samples to examine work-family spillover, daily work and home stressors, and cortisol levels across multiple days. The chronic pain group reported more negative work to family spillover and experienced more instances of stressful home events, particularly avoided arguments. These results align with literature suggesting chronic pain exacerbates tensions in close relationships and increases stress. The chronic pain group also had higher cortisol levels cross late-day periods, indicative of hypothalamic-pituitary-adrenal (HPA) axis dysregulation. This dysregulation is associated with poorer health outcomes, including increased inflammation and psychological distress. We did not find any differences in previously identified cortisol profiles, which are higher-level summaries of cortisol levels within each day. We discuss why such difference might not have appeared in this sample.

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Chronic pain; diurnal cortisol; HPA axis; work and home stressors; work-family spillover; MIDUS

Chronic pain is a leading cause of disability worldwide, yet its unclear pathology and resistance to traditional diagnostics hinder effective treatment and risk factor identification (Dansie & Turk, 2013; Kim et al., 2022). The enigmatic origins of chronic pain complicate prevention efforts and contribute to severe, ongoing stress, increasing the risk of negative health outcomes (Kim et al., 2019; Lunde & Sieberg, 2020). Cortisol is released in response to stress via the hypothalamic-pituitary-adrenal (HPA) axis (Guilliams & Edwards, 2010). Chronic stress can lead to HPA axis dysfunction, which manifests as either hyperactivity or hypoactivity of the HPA axis. This dysfunction can result in abnormal cortisol secretion patterns, such as elevated or flattened diurnal cortisol profiles. Such abnormalities may impair immune function, increase inflammation, and negatively affect cognitive and psychological health, thereby raising the risks of infections, depression, and anxiety (Charles et al., 2020; Riva et al., 2012). These risks are greater compared to those without chronic pain (Petrelluzzi et al., 2008; Van Uum et al., 2008).

Diurnal cortisol profiles, which reflect the pattern of cortisol secretion throughout the day, are crucial indicators of HPA axis function. Normal diurnal cortisol profiles are characterized by a peak shortly after awakening (cortisol awakening response), followed by a steady decline throughout the day, reaching the lowest levels at bedtime. In contrast, abnormal cortisol profiles include Elevated profiles, where levels are higher in early collection periods, and Flattened profiles, where there is a blunted cortisol awakening response and higher evening levels (Dmitrieva et al., 2013; Sephton et al., 2000).

Chronic pain disrupts all facets of life, intensifying stress from the competing demands of work and family, which are key sources of psychosocial stress (Nguyen at al., 2023). Understanding the work-family interface is crucial for revealing how these areas influence cortisol reactivity and dysfunction (Almeida et al., 2018; Kunz-Ebrecht et al., 2004). The conflict from these demands may "spill over," exacerbating stress and increasing the risk of dysregulated cortisol secretion and abnormal diurnal cortisol patterns (Almeida et al., 2016; Krisor et al., 2015; Zilioli et al., 2016).

While there is limited research examining chronic pain, cortisol regulation, and work-family stress simultaneously, studies have explored various combinations of these variables, highlighting their interconnectedness. Chronic pain dysregulates the HPA axis, leading to altered cortisol secretion patterns (Guilliams & Edwards, 2010; Riva et al., 2012). This dysregulation can manifest as flattened diurnal cortisol slopes or elevated evening cortisol levels, indicative of chronic stress and impaired physiological stress response (Dmitrieva et al., 2013; Charles et al., 2020). Work-family stress, including

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work-family conflict (WFC) and negative work-family spillover (NWFS), increases perceived stress and negatively impacts cortisol regulation (Almeida et al., 2018; Zilioli et al., 2016). Higher levels of WFC are associated with elevated cortisol levels and a blunted cortisol awakening response, which are markers of HPA axis dysfunction (Kunz-Ebrecht et al., 2004; Krisor et al., 2015). Additionally, positive work-family spillover can mitigate some negative effects, suggesting a buffering role against stress-induced HPA axis reactivity (Cho & Tay, 2016).

While chronic pain and WFC independently affect cortisol responses, their combined effect is potentially synergistic, suggesting a complex interplay. Research shows chronic pain deteriorates work and family roles, damaging relationships and lowering productivity (Benjamin et al., 2019; Stensland & Sanders, 2018). WFC has been linked to increased pain severity, intensity, and frequency (Baur et al., 2018; Nützi et al., 2015). Although WFC has begun to be examined within diurnal cortisol patterns, as seen in studies like Zilioli et al. (2016), there are no studies that have examined this relationship in the context of chronic pain. This gap suggests a need for more research to understand how WFC impacts cortisol regulation specifically among individuals with chronic pain (Piazza et al., 2018).

This study aimed to examine diurnal cortisol profile differences between adults with and without chronic pain and determine if work stress, home stress, or work-family spillover could predict these profiles within each group. We tested four hypotheses: (1) Compared to those without chronic pain, individuals with chronic pain would report higher work and family stress, more negative, and less positive work-family spillover. (2) Those with chronic pain would experience more abnormal diurnal cortisol profiles. (3) In the chronic pain group, greater negative and lesser positive spillover, along with higher daily stress, would predict abnormal cortisol profiles. (4) Work and family stressors would also predict cortisol profile variations in the non-chronic pain group.

Methods

Participants and procedure

Data were drawn from three projects within a nationally representative longitudinal survey of English-speaking adults in the United States (Midlife in the United States 2; MIDUS II): The initial MIDUS II sample (Ryff & Almeida, 2017), the MIDUS II: Milwaukee refinement sample (Ryff et al., 2024), and the MIDUS II: Daily Stress Project addition (Ryff et al., 2021). Our first inclusion criterion from these surveys was a response to the question identifying those with or without chronic pain ("Do you have chronic pain, that is, do you have pain that persists beyond the time of normal healing and has lasted from anywhere from a few months to many years?"). Removing participants without a response to this question left a subset of 4,537 participants.

For each participant indicating that they have chronic pain (target), we identified a participant indicating they did not have chronic pain (comparison), based on a set of demographic characteristics (age, sex, race, married/cohabiting status, education, employment, and income) and whether and how many valid days of cortisol they had present in the Daily Stress Project data (ensuring that participants with cortisol data were paired). We paired participants by measuring similarity between all target and comparison participants, then assigned each target participant their most similar pair in order of minimal similarity (to improve average similarity). Similarity in this case was average absolute difference between continuous variables, and 0.1 times binary difference (1 if the same category; 0 otherwise) between categorical variables. Before averaging, the indicator for presence of cortisol data was given additional weight to ensure its priority. This resulted in a sample of 1,413 target participants, and 1,413 matched comparison participants. Table 1 shows a breakdown of each match variable between resulting groups. In a logistic regression predicting group (chronic pain or comparison) using these variables, all *p*s ≥.293 (that is, the resulting groups do not differ overall in terms of these features). The code used to prepare data is available at osf.io/kt23x.

Table 1. Demographic characteristics by which the comparison sample was selected.

Characteristic	Chronic pain	Comparison
Sex		
(0) Female	57.608	55.697
(1) Male	42.392	44.303
Race		
(0) Asian	0.283	0.142
(1) Black and/or African American	9.766	11.536
(2) Native American or Alaska Native Aleutian Islander/Eskimo	1.699	1.062
(3) Native Hawaiian or Pacific Islander	0.142	0.071
(4) Other (specify)	2.052	1.345
(5) White	86.058	85.846
Relationship		
(0) Not married or cohabiting	29.158	28.875
(1) Married or cohabiting	70.842	71.125
Employment		
(0) Not employed	45.223	44.515
(1) Employed	54.777	55.485
Age		
Mean	57.272	57.408
SD	12.211	12.271
Years of education		
Mean	13.968	14.005
SD	2.576	2.518
Income		
Mean	60782.142	60902.326
SD	55417.844	53534.529

Means and standard deviations are show for continuous characteristics (age, years of education, and income), and percent of the subsample for each level of categorical characteristics.

Measures

Work-family spillover

Work-family spillover is a measure with 4 factors, each with 4 items. The factors represent different directions and valances: Negative work to family spillover (e.g. "Your job reduces the effort you can give to activities at home?"), Positive work to family spillover (e.g. "Things you do at work help you deal with personal and practical issues at home?"), Negative family to work spillover (e.g. "Personal or family worries and problems distract you when you are at work?"), and Positive family to work (e.g. "Talking with someone at home helps you deal

with problems at work?"). Though the name of this measure refers to family, the items relate to home more broadly, which better matches the work-home distinction made in the stressful event measures. This was collected in the primary MIDUS II study, so there is one observation per person.

The work-family spillover items are generally summed within factors, and this is how versions of the factor scores are provided in the original data, after having missing items mean imputed. To assess model fit within our sample, we imputed missing item values for participants who responded to any items using the Multivariate Imputation by Chained Equation method (MICE; van Buuren & Groothuis-Oudshoorn, 2011), based on all spillover items. We then fit a 4-factor confirmatory factor analysis within our complete dataset, excluding those with no responses to work-family spillover items ($N = 2{,}938$, not paired). This did not fit very well: $x^2 = 2175.299$, $RMSEA = .085$, $CFI = .875$, $SRMR = .089$. For comparison with previous research, we still examined summed factor scores (using our imputations), but also consider items on their own.

Work and home stressors

Work and home stressors are derived from a broader inventory of stressful events (Almeida et al., 2002). There are 4 sets of event items that can be assigned to either work or home: An argument or disagreement, an avoided argument or disagreement, something happening to a close friend or relative, and something else happening at work or school/home. Each set contains questions relating to (1) when the event took place [today or yesterday after the last interview], (2) who the event involved, and (3) how stressful the event was.

One pair of item sets are domain specific, asking if anything happened at work/home. For the other sets, we used the person associated with the event to assign a domain: Events were considered work-related if the associated person was classified as a coworker or fellow student, boss or teacher, employee or supervisee, or a client, customer, or patient. Events were considered home related if the associated person was classified as a spouse or partner, child or grandchild, parent, sibling, other relative, friend, neighbor, religious group member, or family in general.

For each stressor domain, events falling into a domain that were also said to have happened the same day had their stressfulness ratings added to the total domain stressfulness score for the day, which ranged from 0 (not at all stressful) to 3 (very stressful). In addition, ratings from appropriate events reported on the following day that were said to have happened on the previous day were added to the current day's total stressfulness.

Cortisol

Cortisol levels were measured from salivatory samples taken four times a day over a four-day period (see details in the MIDUS II documentation; Petrelluzzi et al., 2008; Skoluda et al., 2016). Saliva cortisol was collected upon waking, 30 min after waking, before lunch, and at bedtime. Samples were self-collected by participants through the aid of written instructions that accompanied each Home Saliva Collection Kit and verbal instructions relayed during telephone interviews. The exact time of saliva collection was noted by each participant with paper/pencil logs and reported during daily telephone interviews. After all 16 saliva samples were completed, tubes were sent to the MIDUS Biological Core at the University of Wisconsin and stored at −60 °C until analysis (Almeida et al., 2009). Compliance was assessed by sample volume and appropriate time of collection, resulting in 97% usable samples (Almeida et al., 2009).

We applied a set of inclusion criteria to days with cortisol to attempt to catch and exclude invalid cortisol data. Some criteria are directly following Dmitrieva et al. (2013): (1) waking time was reported between 4 and 11 AM, (2) total time awake was more than or equal to 12 and less than or equal to 20 hours, (3) all reported waking collection times were after and within 15 minutes of reported waking time, (4) all reported 30-minute after waking collection times were between 15 and 45 minutes after the reported waking collection time, (5) reported lunch time cortisol levels were no more than 10 nmol/L over the after waking level, and (6) all 4 cortisol samples were provided for the day. We deviated from Dmitrieva et al. (2013) with a few additional criteria: (1) no sample was over 120 nmol/L [following Banks (2009); whereas Dmitrieva et al. (2013) used a cutoff of 60 nmol/L], (2) all collection times were in the expected order [waking < after waking < lunch < bed], (3) cortisol was not flagged as being reported on the wrong day, (4) the post waking level was not less than 10 nmol/L over the waking time [indicating the expected awake response was missed], and (5) the bed level was no more than 10 nmol/L over the lunch level [whereas Dmitrieva et al. (2013) compared with the post waking rather than lunch level]. These additional criteria allow cortisol levels to be higher, but ensure they more strictly follow the basic expected pattern.

Cortisol profiles and summaries

Dmitrieva et al. (2013) used a growth mixture model to identify three standard cortisol profiles within the broader MIDUS II Daily Stress Project dataset. To look at these profiles within our subset, we assigned each day with cortisol a profile based on average absolute difference from each standard profile. Figure 1 shows these profiles averaged between our groups, in comparison with the standard profiles. Our subset particularly deviated from the standard profiles in terms of their after waking levels, which is partly due to our looser cortisol level cuttoff. Profiles like this are means of summarizing the cortisol samples within a day into a single value for the day, so we also calculated several alternative summaries, such as area under the curve (with respect to ground; AUCg; Pruessner et al., 2003), cortisol awake response (difference between waking and post waking levels; CAR), slope (standardized linear regression beta weight between collection time and log cortisol levels), and averages of early levels (wake and post-wake) and late levels (lunch and bed).

Analytic approach

We started with one general question to explore across three outcomes: Do groups (chronic pain versus comparison) differ

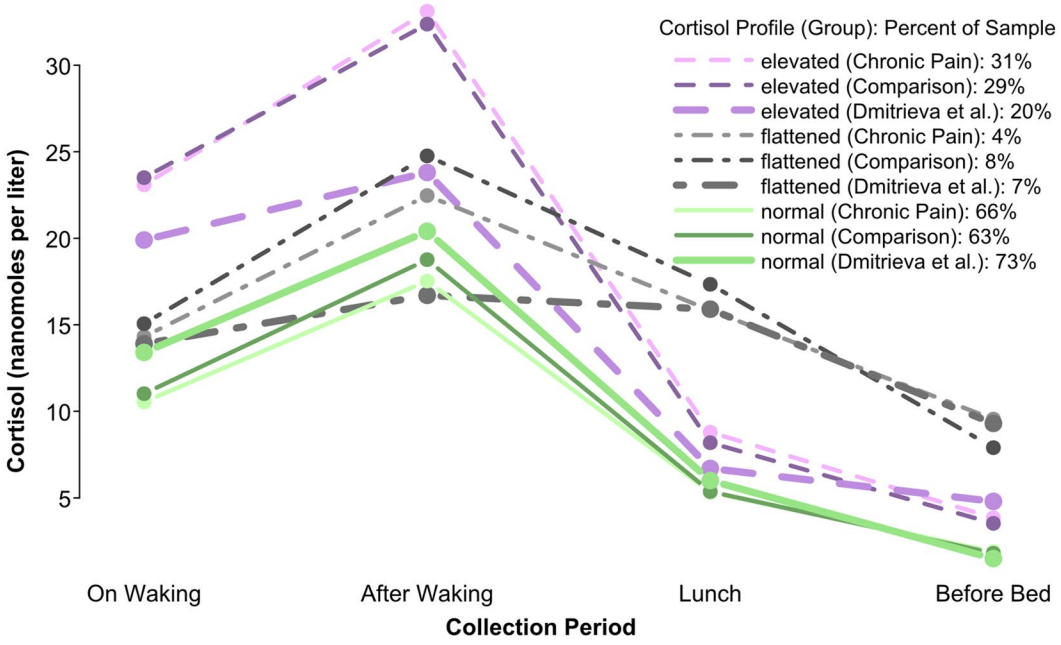

Figure 1. Average cortisol profiles between groups within the current sample (thinner lines), along with those reported by Dmitrieva et al. (2013; thicker lines). Color and line type mark different profiles, and shade marks different groups.

in terms of their reported work-family spillover, work/home stressful events, or cortisol?

Because our primary measures of interest (work-family spillover, work/home stressful events, and cortisol) come from different datasets, we analyzed each within a subset of data with the measure present. For work-family spillover, we retained 1,434 paired participants (717 with chronic pain, and 717 comparisons), with 1 observation per participant. For work and home stress, we retained 1,308 paired participants, with 8 observations per participant. And for cortisol, we retained 660 paired participants, with 4 cortisol days per participant. Retention of the participants with cortisol depended on presence of any valid cortisol days.

Each measure also has a different temporal resolution, so we considered models within all three: person-level models for work-family spillover, day-level models for work and home stressful events, and moment-level models for cortisol samples.

The work-family spillover measures are native to the person level, so this is the level at which we can look at work-family spillover with the most participants retained. At the person level we can also assess group differences with a logistic regression predicting group membership, which is impractical at other levels because group membership does not vary within person.

For all models, we started with a fuller set of covariates, then selected a subset by Akaike Information Criteria (AIC). In addition to some standard demographic variables (including income) and some of the described measures, we included measures of anxiety and self-esteem, which we scaled (z-scored). These are further described in the MIDUS documentation. We imputed missing income and self-esteem values using MICE, based on all other demographic variables and those relating to pain and stressful life events.

Table 2. Work-family spillover item-level logistic regression predicting group membership (positive = chronic pain), selected from all items by AIC.

	Factor	Item summary	*b*	*z*
Intercept			−0.657	−3.310***
B1SF27C	− work to family	Job makes too tired to do things at home	0.191	2.922**
B1SF27I	− family to work	Home responsibilities reduce job effort	−0.251	−3.118**
B1SF27J	− family to work	Personal worries distract you at job	0.279	3.329***
B1SF27M	+ family to work	Talk someone at home helps job problems	0.151	2.524*
B1SF27N	+ family to work	Providing home makes you work harder at job	0.122	2.365*
B1SF27O	+ family to work	Home love makes you confident at job	−0.122	−2.106*

***$p \leq .001$, **$p \leq .01$, *$p \leq .05$.

Results

Work-family spillover

To test for a group difference in person-level work-family spillover, we used a logistic regression predicting group membership from the four spillover measures. In that model, only the negative work to family measure differs between groups ($b = .064$, $z = 2.918$, $p = .004$), where higher negative work to family spillover was associated with the chronic pain group.

We also considered an item-level model: A logistic regression predicting group membership from each item, with items then selected by AIC. As shown in Table 2, six items were retained and differed between groups in this model. Only item C from the negative work to family measure (relating to work being tiring) was retained, whereas both negative and positive family to work measures have multiple retained items, but these are mixed in terms of which group they are associated with: In negative work to family, item J (relating to personal worries being distracting) was associated with the

chronic pain group, but item I (relating to home responsibilities reducing job effort) was associated with the comparison group. In the positive family to work measure, items M and N (relating to emotional support and providing what is needed) were associated with the chronic pain group, but item O (relating to home love and respect) was associated with the comparison group.

One simple interpretation of the item-level results is that those with chronic pain are more prone to be made tired and have more personal worries, which could directly relate to their chronic pain. Otherwise, those in the chronic pain group seem to not be overburdened by home responsibilities, and have emotional support at home.

Work/home stressors

To test for a group difference in daily work/home stressors, we used two, two-level mixed-effects linear regression models with an intercept for each participant, predicting either work or home stress. In each model, we included demographic variables (age, sex, race, and years of education, and income), measures of anxiety and self-esteem, stressful life events measures for both events which occurred within 5 years and more than 5 years ago (which are z-scored), binary employment and married/cohabiting status, household size (number of others in the household), and the opposite stressors measure, along with the binary chronic pain indicator, which is our focal result.

As shown in Table 3, for both home and work stressors, age is associated with fewer stressful events, and non-white race, years of education, and previous stressful life events (recent and distant) are all associated with more stressful events. Being employed is also associated with more work-related, but fewer home-related stressful events. For home stressors, female sex and being married or cohabiting is also associated with more stressful events. Chronic pain is associated with more home, but not more work stressors.

Table 3. Mixed-effects logistic regressions predicting work or home stressors.

	Home stressors		Work stressors	
	b (SD)	*t*	*b (SD)*	*t*
Intercept	−0.455 (0.089)	−5.13***	−0.035 (0.050)	−0.70
Age (-50)			−0.004 (0.001)	−5.75***
Sex (male = 0)	0.267 (0.029)	9.23***		
Race (non-White = 0)			0.078 (0.023)	3.36***
Years of education	0.044 (0.006)	7.65***	0.007 (0.003)	2.16*
Employed (No = 0)			0.160 (0.018)	8.66***
Married/cohabiting (No = 0)	0.122 (0.030)	4.03***		
Stressful life events (within 5 years)	0.058 (0.014)	4.15***	0.031 (0.008)	3.80***
Stressful life events (over 5 years ago)	0.056 (0.014)	3.84***	0.017 (0.008)	2.13*
Anxiety (scaled)	0.031 (0.013)	2.40*		
Self-esteem (scaled)	−0.070 (0.014)	−4.85***		
Chronic pain (No = 0)	0.095 (0.028)	3.42***	−0.011 (0.016)	−0.68
N observations (People)	10464 (1308)		10464 (1308)	
df	10		9	
Conditional R^2	0.147		0.130	
ICC	0.113		0.093	

Excludes variables not selected by AIC. P-values are based on Satterthwaite degrees of freedom.
***$p \leq .001$, **$p \leq .01$, *$p \leq .05$.

Figure 2 breaks this result down to the items that make up the home stressfulness total. From this we can see that the chronic pain group experienced all event types more, but are particularly differentiated in their more frequent experience of avoided arguments.

Cortisol

Figure 3 shows raw moment-level cortisol data, with days colored by the profiles they were assigned. To test for group differences in cortisol, we first used a three-level mixed-effects linear regression model with random intercepts for both person and day within person, random slopes for time since waking and time since waking squared at both random levels, and a binary indicator of post waking period at the person level. This model was predicting log cortisol with some of the same control variables as the previous model (age, sex, race, education, income, anxiety, self-esteem, and stressful life events), and adds controls that theoretically affect cortisol levels: Cigarette smoking (one binary person-level indicator and one daily count), self-rated physical health (person-level), and frequency of pain medication use (person-level, in the last 30 days). In addition to these, we included several time-related variables: Study day (binary indicators for the 3rd, 4th, or 5th day, relative to the 2nd), weekend (binary indicator), wake time, time since waking (collection time – wake time) and time since waking squared (which were scaled), post-wake period (binary indicator, representing the cortisol awake response), and a late period (binary indicator including the lunch and bed periods).

There was no main effect of group in the moment-level model, so we explored period-varying effects using interaction with time or period indicators. There was an interaction with the first order of time since waking (b = .074, t = 2.840, p = .005), but looking at Figure 3, this effect seems driven by the later level, which an interaction between group and later collection periods supports: b = .101, t = 2.975, p = .003. We wanted to see if this effect would show up across dataset levels, and so tested for it with models predicting summed late cortisol levels from the same set of controls and summed early cortisol levels. Table 4 shows all of these models together, with the moment-level model only showing the common control terms. This shows that the cortisol group has higher late-period cortisol levels than the comparison group, and that this difference shows up in cortisol summaries, even when aggregated to the person-level.

Like the chronic pain term in the moment-level model, race and health do not show overall effects, but do have effects at the other levels. As with the chronic pain effect, effects show up in interactions with the late collection periods for both race (b = −.140, t = −3.449, p = .001) and health (b = −.326, t = −3.796, p < .001); that is, both non-white race and poorer health are associated with higher late-period cortisol levels.

We were initially interested in looking at possible associations between chronic pain and assigned cortisol profiles. We used person-level (since that is the lowest level for profiles) mixed-effects logistic regression models predicting each cortisol profile (a binary indicator for the given profile) from

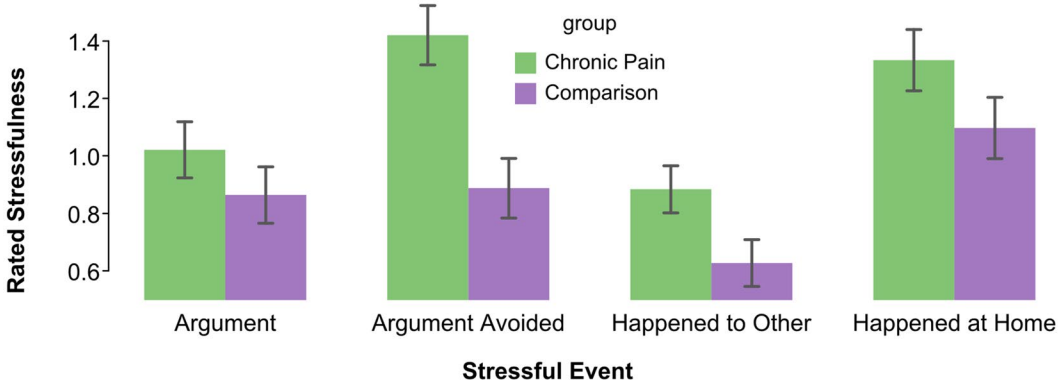

Figure 2. Sum of event stressfulness, which happened at home or with a home-related person. By a logistic regression predicting group with these items, only the Argument Avoided and Happened to Other items reliably differ (*ps* ≤.035).

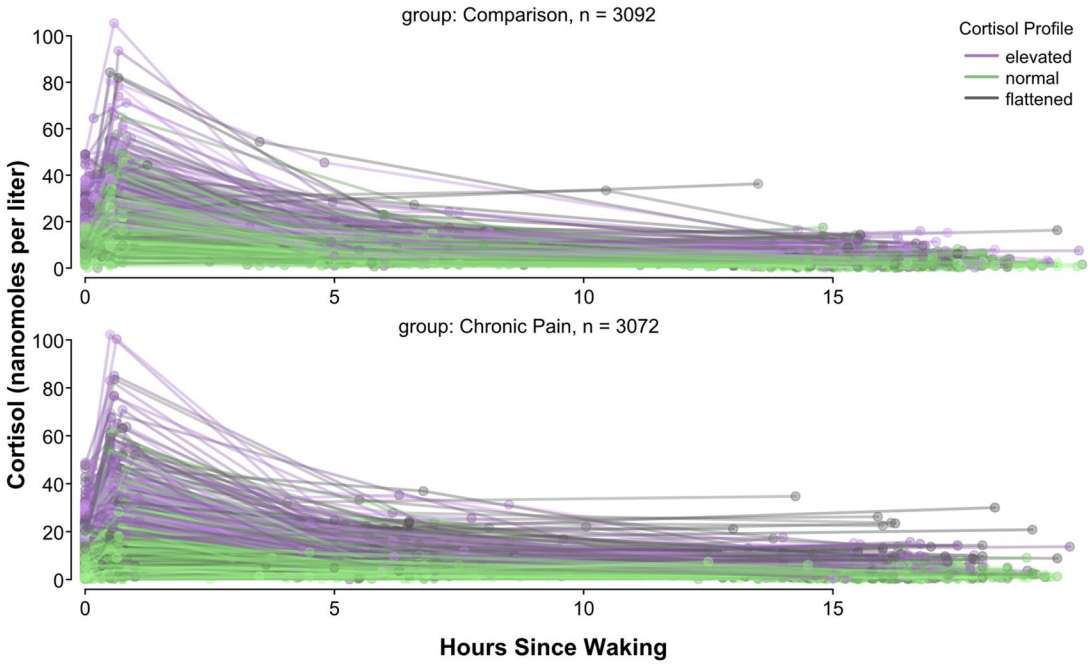

Figure 3. Cortisol days between groups, colored by assigned profile, plotted in order of self-rated physical health.

Table 4. Mixed-effects and regular regressions predicting log cortisol values, either in the moment, or summed between collection periods (early = wake + post-wake values; late = lunch + bed values).

	Moment: cortisol (log)		Day: late cortisol (log)		Person: late cortisol (log)	
	b (SD)	*t*	*b (SD)*	*t*	*b (SD)*	*t*
Intercept	2.240 (0.083)	27.108***	0.941 (0.096)	9.846***	0.744 (0.112)	6.646***
Age (-50)	0.005 (0.001)	4.597***	0.006 (0.001)	5.004***	0.005 (0.001)	4.298***
Sex (male = 0)	−0.108 (0.029)	−3.667***	−0.126 (0.027)	−4.633***	−0.118 (0.029)	−4.016***
Race (non-White = 0)			−0.130 (0.041)	−3.167**	−0.161 (0.043)	−3.702***
Smoker (no = 0)	0.198 (0.044)	4.548***	0.259 (0.040)	6.430***	0.264 (0.044)	5.976***
Health			−0.025 (0.009)	−2.791**	−0.029 (0.009)	−3.086**
Early cortisol (log)			0.343 (0.022)	15.304***	0.439 (0.030)	14.517***
Chronic pain (No = 0)	0.029 (0.028)	1.014	0.065 (0.027)	2.392*	0.064 (0.029)	2.207*
Chronic pain x late period	0.101 (0.034)	2.975**				
N	6164 (1541, 660)		1541 (660)		660	
df	12		9		8	
Cond./adj. R^2	0.873		0.481		0.316	
ICC	0.676		0.327			

Only common and AIC-selected variables are displayed here, which excludes time-related variable from the moment-level model (day, weekend, wake time, time since waking and time since waking squared, and indicators for post-wake and late collection periods), and controls that were not selected in any model. P-values for the mixed-effects models are based on Satterthwaite degrees of freedom.

***$p \leq .001$, **$p \leq .01$, *$p \leq .05$.

group membership to test for such associations, but we did not observe effects for normal ($b = -.206$, $z = -1.113$, $p = .266$), elevated ($b = -.077$, $z = -.443$, $p = .658$), or flattened ($b = .776$, $z = 1.39$, $p = .165$) profiles. The code used to produce all results is available at osf.io/sxjem.

Discussion

The present study aimed to explore the interactions between chronic pain, work-family stressors, and diurnal cortisol patterns. Through our analysis, several key findings emerged: (1) individuals with chronic pain experience more negative work to family spillover (NWFS); (2) individuals with chronic pain experience more stressful home events, particularly with home-related people, with a notable incidence of avoided arguments; (3) individuals with chronic pain exhibit heightened cortisol levels in the later parts of the day, which aligns with patterns associated with poorer health and smoking; and (4) there were no significant differences in standard cortisol profiles between the chronic pain group and the comparison group.

Our findings suggest that NWFS is more prevalent among those with chronic pain. This is consistent with previous research indicating that chronic pain can exacerbate stress, thereby straining the balance between work and family roles (Baur et al., 2018). The complexity of chronic pain's impact on daily life suggests that NWFS could be a result of various interrelated factors, including diminished physical capacity, psychological stress, and the ongoing negotiation of work and family responsibilities. The fatiguing aspect of NWFS seemed to drive group differences in this case, so an intervention aimed at reducing or easing work that may be affected by the specific form of chronic pain may be most effective.

Results indicate that individuals with chronic pain experience more stressful home events, though these events are typically interactions with home-related individuals rather than events occurring within the home itself. A significant portion of these stressful interactions involves avoided arguments. This finding aligns with the literature on chronic pain and interpersonal stress, which suggests that chronic pain can contribute to tension in close relationships, possibly due to the strain of managing ongoing pain and the frustration that can arise from its chronic nature (Nguyen et al., 2023). The prevalence of avoided arguments highlights a potential coping mechanism where individuals with chronic pain might avoid confrontation to prevent further stress, although this could lead to unresolved tensions. Clinically, this finding suggests the importance of integrating family-based or relational therapy into chronic pain management to address and mitigate interpersonal stressors effectively.

The heightened cortisol levels observed in the chronic pain group during the later parts of the day (lunch and bedtime) are indicative of HPA axis dysregulation. This pattern has been associated with poorer health outcomes and behaviors such as smoking (Riva et al., 2012), which can also be seen in our results.

The finding of heightened late-day cortisol levels underscores the importance of addressing HPA axis dysregulation in chronic pain management. Elevated cortisol levels later in the day suggest that the body remains in a state of heightened alertness, which can be detrimental over time. This sustained activation of the HPA axis not only affects physical health by impairing immune function and increasing inflammation but also exacerbates psychological distress, potentially leading to conditions such as anxiety and depression (Charles et al., 2020).

Stress management programs that incorporate relaxation techniques, mindfulness, and coping strategies can help reduce the activation of the HPA axis, thereby lowering cortisol levels. Work-family interventions, such as work-family balance training or work-family integration therapy, can be particularly effective in addressing the specific stressors and challenges related to balancing work and family roles. These interventions offer tools to manage the psychological aspects of chronic pain by teaching strategies to better integrate and manage work and family demands, thereby reducing overall stress and potentially normalizing cortisol levels. For instance, Hammer et al. (2011) demonstrated that work-family intervention programs can significantly reduce work-family conflict, which is a known stressor that can elevate cortisol levels. Similarly, Kelly et al. (2014) found that workplace interventions designed to increase employee control over work time and to improve supervisor support for family and personal life reduced work-family conflict and had positive effects on employee well-being, including stress reduction.

In addition to work-family interventions, Acceptance and Commitment Therapy (ACT) and mindfulness-based stress reduction (MBSR) have shown efficacy in managing chronic pain and reducing stress. ACT focuses on helping individuals accept their pain and commit to living a life consistent with their values, which can reduce the psychological stress associated with chronic pain (McCracken & Vowles, 2014). MBSR, which incorporates mindfulness meditation and body awareness practices, has been shown to reduce stress and improve psychological well-being in individuals with chronic pain (Garmon et al., 2014). These interventions help regulate the HPA axis by promoting relaxation and reducing the physiological stress response.

Integrating these approaches provides a comprehensive strategy for managing chronic pain and associated stress. Work-family interventions address the unique stressors arising from balancing work and family roles, while Acceptance and Commitment Therapy (ACT) and Mindfulness-Based Stress Reduction (MBSR) focus on the broader psychological and physiological impacts of chronic pain. By integrating relaxation techniques, mindfulness practices, and coping strategies specifically tailored to the unique challenges of balancing work and family roles, these interventions can help reduce HPA axis activation and improve overall health outcomes for chronic pain patients. Combining these methods allows interventions to target the multifaceted nature of chronic pain, addressing not only the physiological stress response and psychological well-being but also the critical psychosocial elements of work-family dynamics. This holistic approach can improve overall health outcomes and quality of life for individuals with chronic pain, offering a more effective pathway for managing both the physical and psychosocial aspects of their condition.

Despite our initial interest in standard cortisol profiles as summaries, we did not find profile differences between groups. Considering our other cortisol level findings, this may suggest that standard cortisol profiles are not able to capture some patterns of interest. For instance, the standard flattened profile may have seemed to align with our results because of its elevated late levels, but this was not the case, at least in that flattened profiles did not differentiate our groups.

The lack of a difference in cortisol profiles could alternatively be an indication that cortisol is not as broadly affected by chronic pain as might be expected. This interpretation might suggest a need for personalized approaches to treatment and stress management, as some individuals with chronic pain may experience cortisol dysregulation while others do not. Individual differences like this could uncover adaptive coping mechanisms in regulating cortisol levels, if some behavior could be identified that differentiates more and less affected participants. Furthermore, the lack of a difference in broad cortisol profiles could highlight the need for multi-dimensional assessments of stress and pain, including other physiological, psychological, and behavioral measures, to capture the full extent of HPA axis dysregulation or stress experienced by individuals with chronic pain.

Our findings contribute to the broader understanding of chronic pain and stress physiology by illustrating that while chronic pain influences certain stress-related outcomes like NWFS, home stress, and late-period cortisol levels, it does not necessarily lead to changes in standard cortisol profiles. This could suggest a more nuanced interaction where chronic pain may alter specific stress responses without resulting in distinctly abnormal cortisol profiles. Clinically, this could imply that interventions targeting specific stressors or symptoms might be more effective than those attempting to broadly modulate cortisol levels.

Limitations and future work

Despite the original survey's effort to represent the US population, our sample has particularly more female and more White participants than might be expects, which could limit the generalizability of our results. Future work might especially expand on our finding that non-White participants experience more stressful events in general, and have higher late cortisol levels.

One issue specific to our focal group of those with chronic pain is that there are several variables that also set this group apart, and that are theoretically related to our outcomes of interest, such as aspects of health and health interventions. This presents an opportunity for future research, possibly even within this same dataset, to further probe results to better understand the mechanisms behind the initial group differences.

Future research could also explore intervention methods that address the multifaceted nature of chronic pain and its impact on work-family dynamics and physiological stress responses. Cognitive neuroscientific approaches, such as neurofeedback and brain stimulation techniques, offer potential for modulating pain-related brain activity and enhancing pain management. These interventions could be particularly effective when tailored to address the specific stressors and challenges faced by individuals with chronic pain.

Advances in neuroimaging technologies, such as functional near-infrared spectroscopy (fNIRS) and functional magnetic resonance imaging (fMRI), provide valuable tools for investigating the neurological, behavioral, and psychological characteristics of chronic pain patients. These technologies can help elucidate the brain mechanisms underlying pain perception, emotional regulation, and cognitive processes. Integrating neuroimaging techniques with behavioral assessments and psychological evaluations can offer a holistic understanding of chronic pain and inform the development of targeted interventions. Additionally, wearable technologies and mobile health applications present exciting opportunities for real-time monitoring of pain, stress, and daily activities. These tools can facilitate continuous, objective data collection, allowing for personalized and timely interventions. Future research should leverage these technologies to develop and test innovative interventions that can be implemented in real-world settings.

Conclusion

This study aimed to explore the interactions between chronic pain, work-family stressors, and diurnal cortisol patterns. Key findings include the prevalence of negative work to family spillover and increased stressful home events among individuals with chronic pain, alongside heightened late-day cortisol levels indicative of HPA axis dysregulation. Contrary to expectations, no significant differences in standard cortisol profiles were found between the chronic pain and comparison groups. This suggests that chronic pain does not universally disrupt cortisol rhythms, underscoring the complexity of the relationship between chronic pain and physiological stress responses. These findings highlight the need for personalized, multidimensional intervention strategies that address specific stressors like work-family conflict while integrating therapeutic approaches such as ACT, MBSR, and work-family balance training. By doing so, it may be possible to improve both the psychological and physiological well-being of individuals with chronic pain. Future research should continue to explore these relationships using diverse, longitudinal samples to fully understand the mechanisms at play and develop more effective treatments.

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Data availability Statement

Data is publicly available from the National Archive of Computerized Data on Aging (though the Milwaukee set must be manually requested):

- MIDUS II: icpsr.umich.edu/web/NACDA/studies/4652
- MIDUS II: Daily Stress Project: icpsr.umich.edu/web/NACDA/studies/26841
- MIDUS II: Milwaukee: icpsr.umich.edu/web/NACDA/studies/22840

Code to prepare and analyze the data is available at osf.io/a6es4.

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