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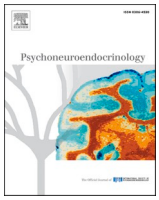

Maternal caregiving stress and metabolic health: Sexual activity as a potential buffer

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ABSTRACT

Chronic stress lead to dysregulation of metabolic hormones, creating risk for obesity and type 2 diabetes. Based on previous work suggesting the potential for sexual activity to relieve psychological stress and reduce stress-related neuroendocrine activity, the present research explored sexual activity as a protective factor. We focused on chronic stress in the form of caregiving stress, comparing premenopausal mothers of a child with an autism spectrum disorder vs. a neurotypical child, in relation to metabolic hormones – insulin (and insulin resistance as assessed by HOMA), leptin, and ghrelin. Then, we explored the moderating role of sexual activity. Our results showed that high-stress mothers showed higher levels of insulin, insulin resistance, and lower levels of ghrelin compared to low-stress mothers. However, sexual activity modulated these associations such that among mothers who were sexually active (as coded from their daily diaries), no significant differences in these outcomes were observed between groups. This buffering effect of sexual activity was distinguishable from the buffering effect of physical activity and independent of global relationship satisfaction. Together, our findings provide novel evidence supporting the potential protective effects of sexual activity from chronic stress-related metabolic disease risk.

Extensive research demonstrates that chronic stress can cause structural and functional changes to the brain, leading to various short-term and long-term health consequences (McEwen, 2017). Some of these changes involve disruptions in the body's metabolic regulation. For example, animal studies have shown that chronic stress is related to changes in the levels of leptin, ghrelin, insulin, and/or insulin resistance (Abizaid, 2019; Morera et al., 2012; Sanghez et al., 2013; Tamashiro et al., 2007) and similar evidence has been found in human studies (Fuller-Rowell et al., 2019; Jaremka et al., 2014; Yan et al., 2016). Given the long-term metabolic health implications of these changes, chronic stress is now a recognized risk factor for obesity and type 2 diabetes (Dallman, 2010; Kelly and Ismail, 2015; Sharma et al., 2022).

Are there any malleable factors that can mitigate the health effects of chronic stress? Considering outcomes related to metabolic health, some studies suggest that physical activity, a well-established health-protective factor (Tsatsoulis and Fountoulakis, 2006), may serve as a buffer. For example, one study found that the link between financial stress and elevated glucose levels was attenuated among individuals who were physically active (vs. inactive; Puterman et al., 2012). Likewise, other studies found that the link between financial stress and prevalence of metabolic syndrome (i.e., a cluster of cardiometabolic risk factors such as obesity and insulin resistance) was significantly reduced among those meeting the weekly physical activity recommendations (especially if sleep recommendations were also met; Kuo et al., 2023); higher levels of weekly physical activity also reduced the relation between job stress (subjective workload) and development of metabolic syndrome over time (Atad and Toker, 2023).

Aside from physical activity, there is limited exploration of other lifestyle factors to protect against stress-related metabolic dysregulation. In the present study, we explore sexual activity as such a buffer. Considered one of the strongest endogenous rewards (Prause, 2019), sexual stimulation is often pursued to cope with stress (Bőthe et al., 2021; Ein-Dor and Hirschberger, 2012). Previous research has indeed documented the benefits of sexual activity, including its stress-relieving effects. For example, sex on a given day has been related to reduced negative affect and stress on a subsequent day, suggesting its affective benefits (Ein-Dor and Hirschberger, 2012; Kashdan et al., 2018). Sexual activity or physical intimacy with a partner also appeared to mitigate stress reactivity, as indicated by reduced blood pressure reactivity (Brody, 2006) or cortisol responses (among women; Ditzen et al., 2019)

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to acute stress. One study also found that even viewing sexually arousing images (vs. neutral images) can reduce cortisol reactivity to acute stress (Creswell et al., 2013).

Nevertheless, whether sexual activity can serve as a protective factor against the effects of chronic stress has received almost no attention, especially in humans. In animal studies, sexually active male rats have been found to show reduced HPA axis response to restraint stress compared to the control rats (Ulrich-Lai et al., 2010). Another study using mice found that sexual activity counteracted the effects of chronic stress on hippocampal cell survival and differentiation (e.g., increased hippocampal expression of brain-derived neurotrophic factor; Kim et al., 2013). To the extent that such changes in neurotrophic function influence metabolic processes (Marosi and Mattson, 2014), this study provides some support to the idea that sexual activity may also affect the link between stress and metabolic health. Nevertheless, no human studies we are aware of have directly examined sexual activity as a buffer against the biological effects of chronic stress. The few existing human studies on the stress-buffering effects of sex have predominantly centered on the *psychological* outcomes (e.g., protection from depression or anxiety during the COVID-19-related lockdown; Mollaioli et al., 2021). Overall, whether sexual activity can protect chronically stressed individuals' metabolic health remains an open question.

1. Research overview

The present research focused on maternal caregiving of children with Autism Spectrum Disorder (ASD) as a form of chronic stress. A meta-analysis has shown that parents of a child with ASD indeed experience greater parenting stress compared to those with a typically developing child or child diagnosed with another disability (Hayes and Watson, 2013). Importantly, this type of caregiving is known to take a toll on caregivers' emotional and physical health (Dijkstra-de Neijs et al., 2020; Masefield et al., 2020) and even increase the risk for mortality (Fairthorne et al., 2014).

We analyzed two waves of data from a study on healthy midlife mothers, half with a child diagnosed with ASD. We examined if mothers caring for a child with versus without ASD (i.e., high- and low-stress mothers) differ in the levels of insulin, a key regulator of glucose metabolism, the body's response to insulin (insulin resistance), as well as levels of leptin and ghrelin, the two hormones heavily involved in appetite regulation. Our main question was the stress-buffering role of sexual activity – that is, if any differences in these outcomes (suggesting more or less healthy metabolic profiles) between high- and low-stress mothers are reduced among those who are sexually active (vs. inactive). We also conducted additional analyses to examine the uniqueness of any sex effects. Specifically, we considered physical activity and global relationship satisfaction as variables that potentially overlap with sexual activity and examined their moderating roles. Finally, we note that our research was exploratory in nature and we did not have specific predictions for each outcome. While previous research using this sample has reported group differences in similar outcomes (using a different subset of participants at different waves; Crosswell et al., 2022; Radin et al., 2019), the potential moderating role of sexual activity, the aim of this study, was never examined.

2. Methods

2.1. Participants and procedure

A total of 183 women between the ages of 20 and 50, with at least one child between the ages of 2 and 16, were recruited for a study on parental stress (see Radin et al., 2019, for more information about the study). Given the study's focus on the impact of stress, our recruitment distinguished between high-stress mothers (mothers with a child diagnosed with ASD, scoring ≥13 on the Perceived Stress Scale [PSS; Cohen et al., 1983]) and low-stress mothers (mothers with a neurologically typical child, scoring ≤19 on PSS. All participants were premenopausal and had no major diseases. Most participants (76%) identified themselves as non-Hispanic White.

The study consisted of four assessments: Baseline, 9-month follow-up, 18-month follow-up, and 24-month follow-up. Participants completed a clinic visit and a 7-day diary study at each time point. Participants had a fasting morning blood draw at each visit. The present analytic sample came from the 18-month and 24-month follow-ups (Time 1 and 2 hereafter), the only waves at which daily diaries included a question about sexual activity.[1] Among 137 participants who participated in the clinic visit and diary study at both time points, we analyzed 101 participants who were consistently sexually active or inactive across the study weeks.[2] In this sample, there were 49 high-stress mothers and 52 low-stress mothers. Table 1 shows that our sample was predominantly white (78%) and highly educated (49% had graduate degrees). We note that no a priori power analysis was conducted for the purpose of this analysis; a summary-statistics-based power analysis showed that a minimum of 87 individuals is needed to detect a level-2 effect of $r = .30$ (Murayama et al., 2022).

3. Key measures

Sexual activity. Every morning during the 7-day diary period, participants indicated whether they had sexual relations the night before (Yes/No). Few participants had more than one report of sex; thus, as in the previous study (Cabeza de Baca et al., 2017), we coded those who had sex at least once during each diary period as sexually active. Across the diaries, 25 participants (25% of the sample) were coded as consistently sexually active and 76 (75%) as sexually inactive. Table 1 shows

Table 1
Participant Characteristics Separated by the Sexual Activity Status.

	Total ($n = 101$)	Sexually Active ($n = 25$)	Sexually Inactive ($n = 76$)	Comparison p-value
Time 1 Background Measures				
Age	43.97 (4.87)	42.72 (5.55)	44.38 (4.60)	$p = .19$
Race				
White	79 (78%)	19 (76%)	62 (79%)	$p = .93$
Black	6 (6%)	2 (8%)	4 (5%)	—
Asian	12 (12%)	4 (16%)	8 (10%)	—
Latino	8 (8%)	2 (8%)	6 (8%)	—
Native American	1 (< 1%)	0 (0%)	1 (< 1%)	—
Education				
< High school	1 (< 1%)	0 (0%)	1 (< 1%)	—
Some college/ bachelor's degree	48 (48%)	13 (52%)	37 (47%)	$p = .87$
Graduate degree	49 (49%)	11 (46%)	38 (50%)	$p = .90$
Stress group (% high stress)	51 (50%)	11 (44%)	40 (53%)	$p = .69$
Body Mass Index (BMI)	25.23 (5.02)	24.52 (3.35)	25.46 (5.46)	$p = .30$
Perceived stress	17.95 (5.73)	17.84 (4.29)	17.99 (6.17)	$p = .90$
Sleep quality	5.50 (3.25)	6.09 (3.58)	5.30 (3.13)	$p = .36$
Diary Measures				
Light exercise (% consistent yes)	63 (85%)	15 (88%)	48 (84%)	$p = .98$
Moderate exercise (% consistent yes)	33 (57%)	9 (64%)	24 (52%)	$p = .62$
Vigorous exercise (% consistent yes)	20 (23%)	7 (35%)	13 (19%)	$p = .24$
Global relationship satisfaction	68.91 (16.00)	75.10 (9.55)	66.63 (17.30)	$p < .001$

Notes. Numbers within the parentheses indicate the proportion of the respective response over the number of available reports. Welch's t-tests and Chi-square tests were conducted for continuous and categorical variables, respectively. Chi-square tests were not conducted for variables with counts < 10.

differences in sexually active and inactive participants in the background and diary measures.

Outcomes. On the fourth day of each diary period, participants visited the clinic and provided a fasting morning blood sample. A registered nurse collected blood from participants using a butterfly needle or IV catheter to assess for a variety of metabolic indicators, including our key hormones of interest as well as cholesterol (total, low-density, and high-density lipoprotein) and triglycerides. Blood plasma and serum were stored at −80 °C for subsequent batch testing.

Insulin and leptin were assayed by RIA (Millipore Sigma, Burlington, MA). The Homeostatic Model Assessment for Insulin Resistance (HOMA-IR; Matthews et al., 1985) was calculated as insulin (μU/ml) × glucose (mg/dL)/405. For plasma leptin, samples were assayed with a radioimmunoassay kit using a ^{125}I- human leptin tracer and human leptin standards from Linco Research, Inc. (St. Charles, MO, USA) in Dr. Peter Havel's laboratory (UC Davis, CA, USA). Ghrelin was assayed by RIA (Phoenix Pharmaceuticals, Burlingame, CA).

4. Baseline measures

We examined if there were systematic differences between mothers who are sexually active versus inactive in Body Mass Index (BMI; based on weight and height measured in the clinic; kg/m^2), perceived stress (assessed using the Perceived Stress Scale; Cohen et al., 1983) or global quality of sleep (assessed using the Pittsburg Sleep Quality Index; Buysse et al., 1989), variables known to be related to metabolic health. Table 1 shows that sexually active and inactive mothers did not differ in BMI, stress, or sleep quality.

5. Diary measures for additional analyses

As variables sharing overlap with sexual activity, we first considered different types of exercise, assessed in the daily diaries as follows: *light exercise* ("I did a few active light exercises"), *moderate exercise* ("I engaged in some moderate activity, where I was working hard enough to raise my heart rate and break a sweat"), and *vigorous exercise* ("I engaged in some kind of vigorous physical activity, where I was breathing hard and fast, and my heart rate had gone up quite a bit"). These binary questions (Yes/No) were presented in the evening diaries with detailed information about what each activity includes. As with sexual activity, we coded people who responded with more than one "yes" during the diary period as those who were active in the corresponding activity. Then as with sexual activity, we coded people who were considered as being active at both time points as consistently engaging in the respective activity. Second, we considered average levels of daily relationship satisfaction as an indicator of global relationship quality. Participants responded to the question, "To what extent were you satisfied with your partner today?" using a slider (0 = not at all, 100 = a lot) in the evening diaries, and an average score across the diary periods (i.e., person mean) was used. Table 1 shows that sexually active mothers did not differ from sexually inactive mothers in terms of physical activity but showed greater relationship satisfaction. Accordingly, we also used relationship satisfaction as an additional covariate in our analyses.

6. Analyses and results

We conducted all analyses in R and multilevel models were fitted using the *lme4* package (Bates et al., 2014). We employed models with a random intercept to examine if high-stress and low-stress mothers differ in metabolic health-related outcomes and if such differences are moderated by sexual activity status. We regressed each of the key outcomes (insulin, HOMA-IR, leptin, ghrelin) on group status (0 = low-stress, 1 = high-stress), sexual activity (0 = inactive, 1 = active), and their interaction, controlling for age, BMI, and time point. As in previous studies (e.g., Jaremka et al., 2014), our outcomes were normalized using a square root transformation.

Table 2 shows that there were significant main effects of the group status, such that high-stress mothers showed higher levels of insulin, HOMA-IR, and lower levels of ghrelin compared to low-stress mothers. However, as illustrated in Fig. 1, sexual activity moderated these effects such that being a high-stress mother was associated with higher levels of insulin ($b = 0.65$, $SE = 0.13$, $p < .001$), HOMA-IR ($b = 0.30$, $SE = 0.07$, $p < .001$), and lower ghrelin levels ($b = -2.05$, $SE = 0.81$, $p = .01$) among sexually inactive individuals, but no such differences were significant among those who were sexually active (insulin: $b = -0.12$, $SE = 0.23$, $p = .59$, HOMA-IR: $b = -0.07$, $SE = 0.12$, $p = .55$, ghrelin: $b = 1.64$, $SE = 1.43$, $p = .25$). All the results remained the same when we additionally controlled for relationship satisfaction, except for the interaction effect in the model predicting ghrelin, which dropped in significance ($b = 3.32$, SE = 1.68, $t = 1.98$, $p = .05$).

6.1. Discriminant analyses

Next, we ran the same set of models, replacing sexual activity with other overlapping variables. When using light exercise, *ps* >.21, moderate exercise, *ps* >.15, or average daily relationship satisfaction, *ps* >.35, in place of sexual activity, we did not find any significant interaction effect. Vigorous exercise, on the other hand, interacted with the group status in predicting insulin ($b = -0.73$, $SE = 0.29$, $p = .01$) and HOMA-IR ($b = -0.39$, $SE = 0.16$, $p = .01$). Specifically, whereas being a high-stress mother was associated with higher levels of insulin, $b = 0.60$, $SE = 0.14$, $t = 4.29$, $p < .001$) and HOMA-IR ($b = 0.29$, $SE = 0.07$, $p < .001$) among those who consistently reported no vigorous exercise, no significant differences based on the stress group status were observed (insulin: $b = -0.14$, $SE = 0.26$, $p = .60$, HOMA-IR: $b = -1.05$, $SE = 0.14$, $p = .45$) among those consistently engaging in vigorous exercise. In other words, vigorous exercise appeared to have similar buffering effects as sexual activity. No interaction involving vigorous activity was found for leptin or ghrelin.

In follow-up models, we included both vigorous exercise and sexual activity and their interactions with the group status as predictors of insulin and HOMA-IR to test their unique effects. Note that the two variables did not completely overlap: 30% of the participants were coded as consistently engaging in one but not the other. We found that both interactions remained significant (sex: $b = -0.82$, $SE = 0.27$, $p = .003$, and exercise: $b = -0.66$, $SE = 0.27$, $p = .02$, for insulin, sex: $b = -0.36$, $SE = 0.14$, $p = .01$, and exercise: $b = -0.37$, $SE = 0.15$, $p = .02$ for HOMA-IR) in the follow-up models, suggesting that the effects of sex and vigorous exercise were independent of each other.

7. Discussion

Although considerable evidence points to the role of chronic stress in the development of obesity and type 2 diabetes mellitus (Dallman, 2010; Kelly and Ismail, 2015), little research has examined its relations with hormones implicated in more proximal metabolic processes among humans. Focusing on maternal caregiving stress, our study showed that chronic stress is associated with higher levels of insulin and insulin resistance (HOMA-IR) as well as lower levels of ghrelin; these findings parallel previous research drawing on the same sample at different time points (Radin et al., 2019; see Research Overview). More importantly, we observed that these associations were attenuated among sexually active (vs. inactive) mothers. That is, the differences between high-stress and low-stress mothers were not significant among mothers who appeared sexually active across the diary periods. Such buffering effects of sexual activity were unique from those of vigorous exercise, which also served a similar moderating role. We did not find any effects of light or moderate exercise. The moderating role of vigorous exercise we observed aligns with previous intervention studies documenting the benefits of exercise training (e.g., decreases in insulin; Dundar et al., 2021), although such work has not necessarily examined exercise as a buffer against stress-related detriments.

Table 2
Results from models testing sexual activity as a moderator of stress group (High vs. Low-Stress Mothers) differences in the outcomes.

	Insulin				HOMA-IR				Leptin				Ghrelin			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
BMI	0.12	0.01	10.43	<.001	0.06	0.01	10.59	<.001	0.26	0.02	16.07	<.001	-0.33	0.07	-4.65	<.001
Stress group	0.65	0.13	4.99	<.001	0.30	0.07	4.43	<.001	0.28	0.19	1.51	.13	-2.05	0.81	-2.52	.01
Sexual activity	0.16	0.18	0.90	.37	0.04	0.09	0.48	.63	0.13	0.26	0.51	.61	-1.43	1.11	-1.29	.20
Stress group × Sexual activity	-0.77	0.26	-2.98	.003	-0.37	0.13	-2.75	.007	-0.40	0.37	-1.06	.29	3.69	1.63	2.27	.02

Notes. $N = 101$ (≥ 194 observations); BMI = Body Mass Index; HOMA-IR = Homeostatic Model Assessment for Insulin Resistance; Stress group was coded as 0 (low-stress mothers) and 1 (high-stress mothers). Sexual activity was coded as 0 (sexually inactive) and 1 (sexually active). All models also include age and time points as covariates.

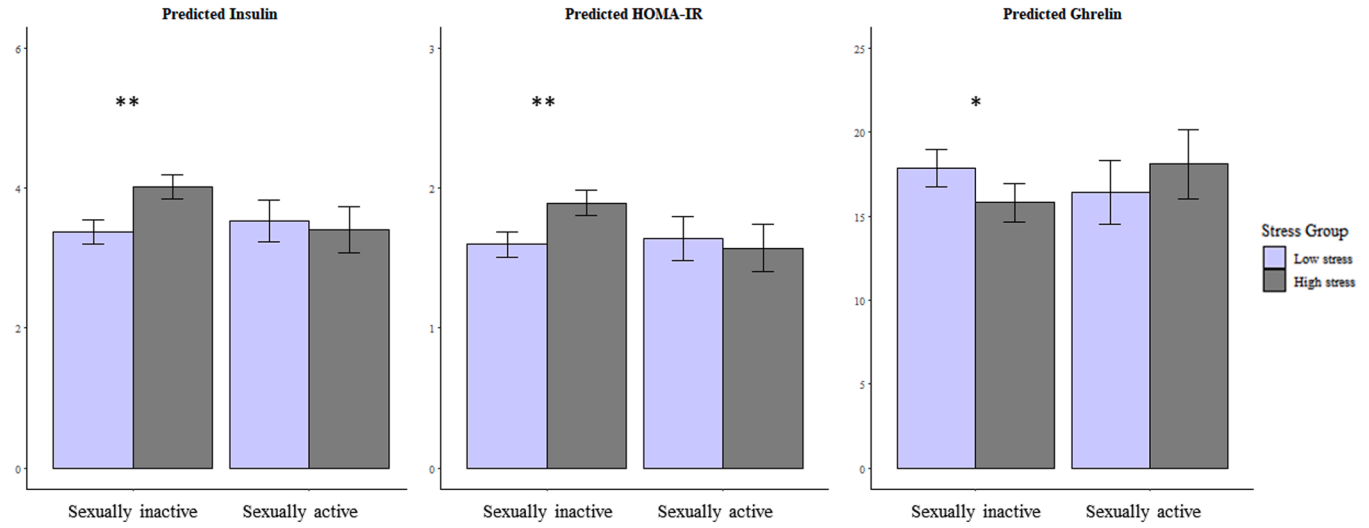

Fig. 1. Sexual activity interacting with stress group (High- vs. Low-Stress) in predicting insulin, HOMA-IR, and ghrelin**.** Notes. Error bars represent 95% confidence intervals. *p <.05. **p <.01.

Our findings on the main effects of chronic stress on metabolic hormones are mostly consistent with previous findings on the relation between other types of chronic stress (e.g., job-related stress; Yan et al., 2016) and outcomes such as insulin resistance. With ghrelin, lower levels have been found among individuals with obesity, type 2 diabetes, or binge-eating disorder (Ukkola, 2009; Pöykkö et al., 2003; Tschöp et al., 2001; Wittekind and Kluge, 2015); evidence for its link with chronic stress appears less consistent (Bouillon-Minois et al., 2022; Daniels et al., 2023; Kim et al., 2015). Here, we found lower levels of ghrelin among chronically stressed (sexually inactive) mothers. These results diverge somewhat from a previous study (Jaremka et al., 2014) which found higher levels of ghrelin in relation to a greater number of daily interpersonal stressors (that arguably resemble caregiving stress). Such divergence may be due to multiple factors including the nature of stressors examined (e.g., daily vs. chronic, social event vs. caregiving-specific), sample characteristics (e.g., yoga experience required in Jaremka et al., 2014), and importantly, timing of the measurement of ghrelin (e.g., blood draw after a meal in Jaremka et al. [2014] vs. fasting morning blood draw in our study capturing stable baseline levels). Indeed, the lack of standardization in the measurement (e.g., timing, collection or storage methods) of ghrelin has been noted as a limitation in the literature, posing challenges to replication (Makris et al., 2017). Thus, we emphasize the need for more research with standardized protocols to draw a more definitive conclusion about the relation between (different types of) chronic stress and ghrelin.

The main finding in our study was the moderating effect of sexual activity on the stress effects. Although a few studies have shown that sex may help relieve subjective experiences of stress and improve mood (Ein-Dor and Hirschberger, 2012; Kashdan et al., 2018), none to our knowledge has shown its impact on stress-related metabolic differences. Although our data do not allow for investigations into the precise mechanisms, there are several possible explanations for the buffering role of sexual activity. For example, sexual activity may protect stressed individuals from poor sleep (e.g., sex at night is related to better sleep quality; Park et al., 2023) or from stress-eating behaviors (e.g., sexual activity or physical affection can reduce food reinforcement and prevent turning to food for stress-coping; Carr and Epstein, 2018). Both sleep quality and stress eating can have substantial effects on metabolism (e.g., Reutrakul & Cauter, 2018; Tsenkova et al., 2013). While sexual activity may also function as a form of exercise that buffers the effects of stress on metabolic health, our discriminant analyses suggest that there may be something unique to sexual activity that cannot be attributed to its physical nature. Overall, the present findings call for further in-depth investigations into the influences of sexual activity on stress responses and the underlying mechanistic pathways.

Our study had several strengths including a novel focus on maternal caregiving stress, the use of multi-wave data, and exploration of protective lifestyle factors including sex and exercise, and covarying relationship satisfaction. Our measure of sexual activity served as an indicator of a relatively stable activity status in that we assessed it over two different weeks, separated by 6 months. Nevertheless, there are important limitations in our study. For one, we assessed sexual activity in a binary manner and let the participants interpret what "sexual relations" indicate. Given that people may have different interpretations of such terms (Sanders et al., 2010; Schwarz et al., 2010) and different sexual experiences may have varying effects on the body (e.g., Krüger et al., 2003), future research should employ more diverse and specific assessments of the sexual activities. Especially in the absence of direct investigations into the mechanisms underlying the effects of sex on stress responses, a more nuanced understanding of the sexual

experiences that do serve the buffering role (e.g., the presence of orgasm) can provide important insights into the mechanistic pathways. Relatedly, the effects of solitary sexual activities may be worth exploring (Goodman et al., 2022). In terms of the sample composition, our study focused on women who were primarily White and all heteroseuxal, highlighting the need to test the generalizability of our findings across different racial groups. Finally, investigations on the metabolic health of the fathers, who also share the caregiving burden, and the role of sexual activity in this population will be important.

To conclude, our study provided novel evidence for the moderating effect of sexual activity in the associations between maternal caregiving stress and metabolic hormones. Given that these metabolic hormones have direct implications for appetite, eating behaviors, and long-term metabolic health (Farooqi et al., 2007; Figlewicz and Benoit, 2009), what lifestyle factors can modulate them in chronically stressed individuals requires more research attention. This study demonstrated the potential for sexual activity to confer benefits, offering a promising avenue for future research.

Footnotes

[1]Between 18 and 24 months, a subset of mothers participated in a mindfulness-based intervention. There were no significant differences in participation status based on the sexual activity status, $\chi^2(1) = 0.25$, $p = .61$, and adjusting for participation status had no influence on our findings.

[2]We considered sexual activity status as a between-person variable given that a) as assumed in previous cross-sectional research (e.g., Zhang and Liu, 2020), any health benefits of sexual activity are likely to be accumulative, and b) practically, we could not reliably disentangle the within-person and between-person effects of sexual activity with only two observations (i.e., addressing if there is an effect of being sexually active at a given timepoint above and beyond general tendencies to be sexually active). Thus, we focused on individuals who were consistently active or inactive, minimizing the potential for within-person fluctuations to confound the effects of consistent sexual activity.

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CRediT authorship contribution statement

Elissa S Epel: Methodology, Project administration, Writing – review & editing, Funding acquisition. **Michael A Coccia:** Project administration, Writing – review & editing. **Aric A Prather:** Writing – review & editing, Methodology, Project administration. **Yoobin Park:** Formal analysis, Writing – original draft, Conceptualization, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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