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# Daily physical activity and menopausal hot flashes: Applying a novel within-person approach to demonstrate individual differences

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## Abstract

**Background—**Physical activity (PA) may be a useful tool in the management of menopausal hot flashes (HFs) but findings are generally inconsistent. There are few well-designed and sufficiently powered RCTs. Applying a longitudinal within-person approach offers an alternative way to examine the PA-HFs relationship which enables complete accommodation of inter-individual differences.

**Objectives—**Aprospective daily diary study which applied experience sampling methods and time series modeling techniques investigated, at the within-person level, the relationship between objectively measured daily PA of varying intensities and self-reported menopausal HFs.

**Methods—**Twenty-four symptomatic middle-aged women (*M* age = 50.4; SD = 4.9) completed fitness, body composition and hormonal status screening, and reported on daily HFs using an electronic PDA device across one menstrual cycle or for 30 days (if postmenopausal). Daily PA and PA intensity was measured using accelerometry and subjects completed a battery of psychological measures.

**Results—**Within person analysis identified significant relations between PA and HFs in 50% of subjects, although the specific PA indicators that predicted HFs varied, both in terms of direction and magnitude. Perceived control over HFs was the variable that most consistently differentiated



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**Competing interests** The authors declare that there are no conflicts of interest.

**Appendix A. Supplementary data** Supplementary data associated with this article can be found, in the online version, at doi: 10.1016/j.maturitas.2011.12.011.

between women for whom more PA was associated with fewer HFs as compared to those for whom more PA was associated with more HFs, but other individual difference characteristics such as affect, depressive symptoms, and anxiety were identified.

**Conclusions—**There is great individual variation in the way daily PA impacts self-reported HFs. Affective outcomes and perceived control may help potentially explain this variability.

### Keywords

Physical activity; Hot flashes; Vasomotor symptoms; Individual differences

## 1. Introduction

Most middle-aged women experience vasomotor symptoms such as hot flashes (HFs) and night sweats as they transition through menopause. The reporting of vasomotor symptoms increases as women transition through menopause, lasting on average >5 to 8 years and peaking during late perimenopausal and early postmenopausal years [1,2]. Women who experience menopausal HFs also report decreases in well-being and quality of life [3] and are more likely to report depressive symptoms and sleep problems [4,5]. Although effective hormonal therapies exist, many women are reluctant to take them and prefer alternative, more natural ways of coping with HFs.

There is some evidence that regular physical activity (PA) may be an effective means to deal with the adverse consequences of the menopausal transition, but the relationship between PA and vasomotor symptoms in particular remains unclear and even controversial. Whereas different potential pathways exist along which PA could act on vasomotor symptoms (including neuroendocrine [6–8], body composition, thermoregulation, fitness and mood [9] effects), there is inconsistent evidence. Several cross-sectional studies have indicated that PA may reduce vasomotor symptoms because more active women also report fewer symptoms [10,11]. Some prospective studies however failed to support this association [12]. There are few well-designed and adequately powered randomized controlled trials (RCTs) and the evidence available to date is insufficient to conclude whether exercise is an effective means for treating HFs [13]. Moreover, at least one randomized controlled trial found that moderate-intensity exercise may actually slightly increase vasomotor symptoms in some women [14]. Another laboratory study has shown an increase in objectively measured HFs following exercise [15] and self-reports of higher perceived physical exertion preceded HFs in a study involving two days of ambulatory hot flash monitoring in a real-life setting [16]. On the other hand, some evidence suggests that low-intensity exercise such as yoga may be beneficial [17], although a recent review of available evidence to date failed to find systematic effects for this modality [18]. Clearly, more data are needed to evaluate the effects of PA on vasomotor symptoms and to consider the differential impact that PA of varying intensities may have. Similarly, more data are needed to examine factors that may modify the relationship between PA and HFs, including physiological differences (e.g., fitness, fatness, hormonal status), personality characteristics linked to symptom reporting (e.g., neuroticism), or psychological factors known to impact symptom and physical activity experiences (e.g., affect or perceived control) [19].

The limited understanding of the PA and HFs relationship and the inconsistency in past research are partially attributable to various methodological shortcomings of existing studies. These include failure to account for potential confounding factors (health status, menopausal/hormonal status, weight/fitness status, SES, race/ethnicity, smoking), heterogeneity in measures used, lack of objective assessment of vasomotor symptoms and PA, and heterogeneity (subject-specificity) of the effects of PA [17,20,21]. Traditional

between-subjects designs typically require large samples sizes to accommodate sub-group analyses or be able to control adequately for potentially confounding factors, but may not be sufficient to control for subject-specificity of the effects of PA. Whereas there is a clear need for a large, adequately powered RCT comparing the effects of exercise or PA to a non-exercise or other adequate comparison group [20], longitudinal within-person designs are essential in uncovering subject-specificity of the effects of PA and also may be helpful in revealing the causal association between PA and symptoms such as HFs.

Studies applying experience sampling methods conduct frequent "in-real-time" measurements to minimize the impact of retrospective bias and capture emotional and psychological phenomena in "real life" settings [22]. We propose that application of these techniques may be particularly suitable for studying the dynamic patterns underlying symptom experiences within persons over time, as well as differences due to variations in levels of daily PA. Thus, the purpose of this study was to apply a within-subject replicated time series design and experience sampling methods to examine individual differences in daily vasomotor symptom reporting as a function of daily fluctuations in objectively measured PA. We also examined, in a descriptive fashion, the influence of relevant physiological (fitness, BMI, body fatness, hormonal status), personality, and psychological (affect, stress, perceived control) factors that may help characterize the individual differences in the within-person relationships.

## 2. Materials and methods

### 2.1. Participants

Middle-aged women experiencing menopausal HFs were recruited from volunteers who responded to advertisements posted in local newspapers, physician's offices, and online listservs. Participants ($N = 24$) were healthy perimenopausal or postmenopausal women who reported experiencing menopausal hot flashes (5–20 per day) within the last 2 weeks. Classification of menopausal status was based on self-reported menstrual history using the STRAW staging criteria [23], with perimenopausal women reporting irregular (≥7 days different from normal) or infrequent (≥2 skipped cycles or ≥60 days but less than 12 months of amenorrhea) menses in the past 12 months and postmenopausal women reporting no menses in the past 12 months. Exclusion criteria included smoking, previous or current use of any form of hormonal therapy, bilateral oophorectomy, heavy exercise (≥10 h per week of aerobic exercise), functional limitations or inability to perform normal PA, extremes of body weight (body mass index <18 or >35), cardiovascular disease, metabolic disease, uncontrolled thyroid disease, chronic menstrual cycle irregularity or other uterine/ovarian problems that can impact menstrual bleeding, history of affective disorders and use of antidepressants and beta-blockers.

### 2.2. Measures

**2.2.1. Baseline assessment—**All participants completed baseline assessments which included demographic and health history information and a battery of different psychosocial questionnaires. All questionnaires were previously validated measures and demonstrated acceptable internal consistency in this study (Cronbach's $\alpha = 72$ to .89). Affect was assessed using the Positive and Negative Affect Schedule (PANAS) [24]; depressive symptoms were assessed using the Beck Depression Inventory (BDI) [25]; chronic stress was assessed using the Perceived Stress Scale [26]; perceived control over HFs was assessed using the Perceived Control Index (PCI) [27]; personality was assessed the well-established NEO-FFI [28] (neuroticism, extroversion, openness, agreeableness, and conscientiousness), the Life Orientation Test (LOT-R) [29] (optimism and pessimism), and the State-Trait Anxiety

Inventory Form T (STAI-T) [30] (trait anxiety). Detailed description of the measures and procedures for deriving scores are available in Online Appendices.

Additionally, all women completed two screening visits at the General Clinical Research Center which included a physical examination, blood draw, weight and height measurement, body composition assessment using dual energy X-ray absorptiometry (DXA; DXA; Hologic QDR 4500W; Enhanced Whole-Body6 Analysis software version 5.71), and a maximal graded exercise test during which expired gases were collected (using TrueMax2400 Parvomedics Inc. metabolic system, Salt Lake City, UT) for the assessment of cardiorespiratory fitness using a modified Balke treadmill test [31].

Concentrations of reproductive hormones were measured from two 10-h fasted blood samples (collected between 7:30 and 10:00 am) and from daily urine samples. Blood samples were allowed to clot for 30 min at room temperature, and centrifuged at 3000 rpm for 15 min at 4 °C. All samples were analyzed by Quest Diagnostics. Follicle stimulating hormone and luteinizing hormone were analyzed using immune-chemiluminometric assay with analytical sensitivity of 0.07 IU $L^{-1}$ and 0.7 IU $L^{-1}$ for follicle stimulating hormone and luteinizing hormone, respectively.

Daily estrogen and progesterone exposure was assessed from daily urine samples. All urine samples were corrected for specific gravity using a hand refractometer (NSG Precision Cells) to account for hydration status [32]. Microtiter plate competitive enzyme immunoassays were used to measure the urinary metabolites estrone 1 glucoronide (or E1Gwhich is the best analyte in urine to reflect 17 Beta estradiol) and pregnenediol glucuronide (or PdG which is the best reflection of serum progesterone) as previously reported [33]. Because the number of days in which urine samples were collected varied across women, averages of the daily concentrations of both urinary estrogen (E1G) and progesterone (PdG) were used in the analysis.

**2.2.2. Daily measures—**Participants carried an electronic PDA device (Tungsten E2) and were asked to enter each hot flash experienced during the day. The Purdue Momentary Assessment (PMAT) platform was used to collect the data [34]. Women entered each hot flash as a separate event (time-stamped automatically by the PDA) and each time provided contextual information such as how long ago the hot flash occurred, its duration, severity, etc. The data were downloaded on to a computer and processed to determine the total number of reported unique hot flash events per day.

Daily PA was objectively measured using a uniaxial accelerometer (Actigraph model GT1M, Pensacola, FL) that was positioned over the participants' non-dominant hip with an adjustable elastic belt. Participants wore the accelerometer for the entire data collection period (i.e., either 30 days or for the duration of one menstrual cycle) and were asked to take off the accelerometer during bathing, swimming, or when in contact with water. The accelerometer collected data in 1 min epochs and the data were processed and analyzed using the ActiLife data analysis software from Actigraph (version 5.1.5). Data were validated for wear-time (valid hour had ≥10% of non-zero activity, valid day had ≥10 valid hours) and total daily physical activity counts, percent time spent being sedentary and engaged in light, moderate, and vigorous activity were determined based on criteria established by Matthews [35].

## 2.3. Procedures

Women were scheduled for two screening visits. The first screening visit (between menstrual cycle days 2 and 5) included informed consent procedures, blood draw, resting EKG, and questionnaires. The second screening visit (a week later) included a physical

examination, DXA, and a maximal graded exercise test (GXT). Next, participants attended a study familiarization visit and started their daily data collection. Daily data collection using PDAs and accelerometers started on the first day of the next menstrual cycle (when applicable) and continued until the next menstrual cycle or for a period of 30 days for non-menstruating women. To determine hormonal exposure, daily urinary samples were collected.

### 2.4. Data analysis

The within-person analysis involved analyzing data for each woman separately and was repeated four times for each type of physical activity (PA) predictor (i.e., total daily PA, sedentary time, light intensity PA, moderate intensity PA, vigorous intensity PA). Analysis of both cross-lagged (i.e., effects of previous day's physical activity on next day's hot flash frequency) and simultaneous (i.e., relation between same-day physical activity and hot flash frequency) effects was performed.

The basic data in the within-person analyses consists of a bivariate time series for each of the 24 women. Each bivariate time series is composed of repeatedly measured Daily Hot Flashes (DHF) and Physical Activity (PA: referring to either total daily PA, sedentary time, light PA, moderate PA, or vigorous PA in each separate analysis) and is modeled for each individual participant according to the following dynamic model:

$$\mathrm{DHF}(t) = \beta_{\mathrm{DHF}\rightarrow\mathrm{DHF}} \times \mathrm{DHF}(t-1) + \beta_{\mathrm{PA}\rightarrow\mathrm{DHF}} \times \mathrm{PA}(t) + e_{\mathrm{DHF}}(t)$$
$$S(t) = \beta_{\mathrm{PA}\rightarrow\mathrm{PA}} \times \mathrm{PA}(t-1) + e_{\mathrm{PA}}(t)$$

The DHF at each day $t = 1, 2, \ldots, T$ (where $T$ is the maximum number of days at which a given participant has been repeatedly measured), denoted by DHF($t$), is regressed on the DHF at the previous day, DHF($t-1$), and on PA at the previous day, PA($t-1$). The regression coefficient $\beta_{\mathrm{DHF}\rightarrow\mathrm{DHF}}$ associated with the regression of DHF($t$) on DHF($t-1$) reflects the stability of DHF scores across days. The regression coefficient $\beta_{\mathrm{PA}\rightarrow\mathrm{DHF}}$ quantifies the effect of the PA level at previous day $t-1$, PA($t-1$), on DHF($t$). This so-called cross-lagged regression coefficient $\beta_{\mathrm{PA}\rightarrow\mathrm{DHF}}$ is the parameter of main interest in the time series analyses. Please note that an estimate of $\beta_{\mathrm{PA}\rightarrow\mathrm{DHF}}$ is obtained for each individual participant.

The time-dependent fluctuations of PA are described by the second equation in which the regression coefficient $\beta_{\mathrm{PA}\rightarrow\mathrm{PA}}$ reflects the stability of PA scores across days. The terms $e_{\mathrm{DHF}}(t)$ and $e_{\mathrm{PA}}(t)$ denote process noise associated with, respectively, DHF and PA. It is assumed that $e_{\mathrm{DHF}}(t)$ and $e_{\mathrm{PA}}(t)$ lack any sequential dependencies, but are allowed to be correlated at each day. This correlation cor$[e_{\mathrm{DHF}}(t), e_{\mathrm{PA}}(t)]$ reflects the contemporaneous relationship (i.e., the relationship occurring within each day) between same-day DHF and PA. For a bivariate observed time series it is not possible to establish the causal direction of this instantaneous relationship.

The total number of repeated measurements available for each participant was rather small ($T$ ranged from 26 to 59 occasions across the subjects, with an average $T = 32.8$, $SD = 7.6$). This total number is even further reduced due to the presence of missing data (missing data are imputed by means of a standard time series analysis technique; cf., e.g., Refs. [36]). Hence, in order to obtain a reasonable power for the statistical significance tests to be reported below, we use a slightly larger nominal alpha associated with a nominal $t$-test value of $t_{\mathrm{nom}} = 1.5$.

In order to describe the influence of relevant physiological, personality, and psychological factors that may help characterize the individual differences in the within-person relationships, we subsequently grouped the women into two groups based on the direction of the relationship between daily hot flashes and physical activity (i.e., positive or negative cross-lagged regression coefficient, $\beta_{PA \rightarrow DHF}$, as derived from the within-person analysis of each of the physical activity predictors). Using *t*-test statistics we then examined differences in mean levels of physiological predictors (fitness, BMI, fatness, FSH, E2), personality variables (NEO-FFI domains, optimism, pessimism, trait anxiety), and psychological outcomes (affect, depressive symptoms, perceived stress, and perceived control) between the two groups across each physical activity indicator (total daily physical activity, sedentary time, light PA, moderate PA, vigorous PA).

## 3. Results

### 3.1. Sample description

The demographic description of the sample ($N = 24$; $M$ age = 50.4; SD = 4.9) is presented in Table 1. The sample was predominantly white, married, well-educated, and with average or above average household income. The level of cardiorespiratory fitness was highly variable in the sample but overall within the typical ranges seen for this age group. The BMI and body fatness values were also variable but based on BMI, nearly 74% of the women would be categorized as normal weight. Based on FSH values, 60% women could be considered postmenopausal (FSH > 40 mIU/ml) [37]. Using self-reported menstrual bleeding history and the STRAW staging criteria 60% of women could be categorized as perimenopausal (5 early perimenopausal and 9 late perimenopausal) and 40% as postmenopausal (5 early postmenopausal and 5 late postemopausal).

### 3.2. Daily physical activity and daily hot flashes

Two subjects did not report any HFs during the study period in spite of being symptomatic during screening and were generally non-compliant with the PDA protocol. The actigraph monitor did not provide useable data for one additional subject. Another subject had more than 50% missing actigraph data due to unit failure and was excluded from the analysis. The within-person time series analysis of data from the remaining 20 participants revealed substantial individual differences in the observed relationships between objective daily estimates of PA and daily hot flash frequency.

Overall, there were statistically significant relations between PA and hot flash frequency (either cross-lagged or same-day) in half of the subjects (10 out of 20). However, for both cross-lagged and same-day associations there was substantial variability in both the direction and magnitude of the effects. Cross-lagged coefficients presented in Table 2 reveal this variability in the relationship between a previous day PA estimates and the next day's hot flash frequency. Overall, the sample was split in half in terms of the direction of the associations (positive versus negative cross-lagged effects) detected between objective PA indicators and subsequent hot flash frequency. Total daily PA (referred to as PA counts in Table 2) significantly predicted next day's hot flash frequency for three women (positively). Sedentary time predicted HFs significantly for two women (negatively). Time spent in moderate intensity PA predicted HFs positively in two women. Only 15 women performed any vigorous PA based on our criteria and the overall amount was very small. Time spent in vigorous PA predicted HFs positively for one woman and negatively for two women.

Relative to same-day associations between daily PA estimates and daily self-reported HFs, approximately half of the women daily PA counts were associated with daily HFs positively and for the other half negatively. The associations were statistically significant for five

women, with 4 women showing positive associations and one woman showing a negative association (data for all subjects presented in Table 3 in Online Appendices). Examination of the autoregressive coefficients indicated that on a daily timescale, both hot flash frequency and PA can be characterized as having fairly low level of consistency from day to day (data available from authors upon request).

### 3.3. Characterizing individual differences

The characteristic that most consistently differentiated between women whose daily activity appeared to be negatively associated with HFs as compared to those whose daily activity was positively associated with HFs was perceived control over hot flashes. Women for whom previous day's PA was linked with fewer subsequent HFs exhibited a higher level of perceived control. These differences were statistically significant for relationships between vigorous PA and HFs ($t_{13} = 2.484$, $p < .05$) and for relationships between moderate PA and HFs ($t_{19} = 2.217$, $p < .05$). There was a trend for these differences to be significant also for overall physical activity ($t_{19} = 1.876$, $p = .076$) and sedentary time ($t_{19} = -1.918$, $p = .070$).

Pessimism differentiated significantly between women with positive and negative relationships between light intensity PA and HFs ($t_{19} = 2.166$, $p < .05$), such that women for whom previous day's light intensity activity predicted more HFs the next day had lower levels of pessimism. Depressive symptoms differentiated between women for moderate ($t_{19} = 2.217$, $p < .05$) and vigorous ($t_{13} = -2.213$, $p < .05$) physical activity. Namely, women with positive relationship between moderate intensity PA and next day's hot flash frequency reported fewer depressive symptoms as compared to women who showed a negative relationship between moderate activity and HFs. The relationship was opposite for when considering the effect of vigorous activity on HFs. Women with negative association between vigorous PA and subsequent hot flash frequency had fewer depressive symptoms, more positive affect ($t_{13} = 3.288$, $p < .01$), lower levels of trait anxiety ($t_{13} = 2.198$, $p < .05$), higher E1G levels ($t_{13} = -2.361$, $p < .05$), and as previously noted also higher perceived control. Borderline differences were also found for total percent body fat ($t_{13} = 2.132$, $p = .053$), trunk percent body fat ($t_{13} = 1.838$, $p = .089$), LH levels ($t_{12} = -2.039$, $p = .064$), and conscientiousness ($t_{13} = 1.831$, $p = .090$) between women for whom vigorous PA was associated with fewer subsequent HFs versus those for whom vigorous PA was associated with more subsequent HFs.

## 4. Discussion

This study applied a novel within-person approach to characterize individual differences in the relationship between PA and self-reported HFs. The results unveiled high subject-specificity in the effects of PA on HFs and suggested that there may be subgroups of women that are affected differently by PA when it comes to self-reported hot flash frequency. These findings help to explain the inconsistencies in literature regarding the relationship between PA and menopausal HFs. The study contributes meaningfully to the literature because it links for the first time objectively measured PA and self-reported HFs, uses in-real-time symptom reporting to reduce retrospective bias, and demonstrates that substantial individual differences exist in the way PA affects hot flash reporting during the menopausal transition. These results may have important implications for designing and evaluating the effectiveness of PA interventions targeting menopausal symptoms.

Previous research provides limited evidence that PA is beneficial for reducing menopausal vasomotor symptoms (e.g., Refs. [13,20]). In our previous work we identified differential patterns of symptom experiences across a 4-month exercise trial [38]. These differences impacted the extent to which women benefited from the intervention on a number of mental health and quality of life outcomes [38], and were linked to differences in optimism and

marginally also to changes in cardiorespiratory fitness [39]. The results of the present study further support these individual differences, and the high subject-specificity of effects demonstrated in this study suggest that the differences in symptom reporting in response to PA may be even more pronounced than anticipated. Traditional between-subject designs are rarely able to accommodate all individual difference variables linked to outcomes under study. The within-subject design employed in this study is more advantageous in this respect in that it allows for testing of subject-specificity with each subject serving as his/her own control. Noteworthy is also the fact that the heterogeneity of effects was demonstrated in this study using an objective measure of daily PA, thus removing the shared method-variance of self-reported physical activity and hot flash symptoms which was typical of previous studies [13,17,20].

Although this study was not powered to detect between-person differences, the descriptive analysis revealed some characteristics that may serve as potential targets for identifying commonalities in symptom experiences among subgroups of women which should be pursued by further research. Body fat percentage and differences in levels of certain reproductive hormones helped explain differences in the effects specific to vigorous PA. That is, women for whom more vigorous PA predicted fewer subsequent HFs tended to have higher adiposity (both total body and trunk), had lower levels of LH and higher levels of E1G (urinary analyte reflecting17 Beta estradiol) as compared to women whose vigorous PA predicted more HFs. This finding is consistent with the “thin hypothesis” positing a protective effect of adiposity on vasomotor symptoms due to the fact that adipose tissue acts as a site of estrogen production after menopause [9]. However, it is in contradiction to more recent studies supporting the thermoregulatory models of HFs. Based on the thermoregulatory hypothesis [40,41], performing vigorous physical activity should stimulate more HFs because it results in markedly increased body core temperature. These effects should also be more pronounced for women with higher adiposity, as supported by other studies showing a positive association between vasomotor symptoms and body mass index [12,42] as well as recent data from the SWAN study demonstrating higher odds of reporting vasomotor symptoms for women with higher levels of body fat [43] (subcutaneous, in particular [44]) and more HFs associated with body fat gain [45]. Curiously, we observed “protection” of adiposity when assessing impact of vigorous activity. Our outcome measures were self-reported HFs and different results may ensue from studies involving objective measures of vasomotor symptoms (area of research we are currently actively pursuing). Subjective and objective measures of HFs are highly discordant [46,47] and it remains to be determined how PA of different intensities impacts objectively measured HFs.

Commensurate with other studies, perceived control over HFs was higher for women whose PA was negatively associated with hot flash frequency [48,49]. Women whose vigorous PA was negatively associated with hot flash frequency also had lower levels of trait anxiety, depressive symptoms, more positive affect, and tended to be higher in conscientiousness. Prior research has frequently demonstrated a negative correlation between self-reported psychological health and physical symptoms [50,51]. In addition, conscientiousness is negatively correlated with somatic symptom reports, likely due to its association with health-enhancing behaviors [52] (including PA [53]) and increased stress tolerance [54], although individuals high in conscientiousness may be less willing to admit to symptoms [55]. Somewhat surprisingly, neuroticism did not differentiate in trajectories of the associations between PA and HFs. Many between-subject studies have demonstrated a strong positive association between neuroticism and somatic symptoms [56]. It may be that within individuals, neuroticism’s impact on symptom reports may wax and wane. Alternatively, neuroticism may not predict the report of some kinds of symptoms, particularly those with a thermodynamic component [39]. Somewhat counterintuitive were the findings regarding higher levels of pessimism and depressive symptoms for those

women whose activity (light and moderate, respectively) predicted fewer HFs. It is plausible that these women may use PA to self-regulate their symptoms, but this speculation should be tested in future research.

Although our study design precludes drawing any causal inferences, the potential involvement of these psychological characteristics is consistent with the biopsychosocial model of HFs [57], suggesting that PA may be most effective as a treatment option when combined with cognitive behavioral strategies aimed at restructuring beliefs about HFs such as perceived control. Any such approach should, however, be informed by analysis of individual differences so that person-specific recommendations can be formed regarding avoidance of behaviors and contexts that trigger symptoms, as well as the development of effective coping strategies to minimize the impact of bothersome symptoms on normal daily functioning, particularly in the context of behavioral pursuits such as PA.

To our knowledge, this is the first study to link objectively measured physical activity to self-reports of vasomotor symptoms. Given the small and racially homogeneous sample, our findings should be interpreted as preliminary and await further corroboration. It is possible that there may be additional systematic effects which did not attain significance in this study due to the limited power of the rather short time series. The analysis of between-person differences in physiological, personality, and psychological characteristics was purely descriptive and future research is needed to evaluate the validity of our conclusions. Our findings regarding differential effects of PA of different intensities are also preliminary and likely dependent on our operational definition of intensity. We adopted categorization which was shown to be valid in samples of adults based on cutoffs proposed by Matthews [35], however, different categorization (e.g., Ref. [58]) may alter the study conclusions. Future studies should incorporate combinations of different measures and categorizations to rule out that findings are due to a particular method of assessment. Future studies should also sample PA and vasomotor symptoms over longer periods (intermittently or continuously) to characterize patterns of both across different stages of the menopausal transition. Our study emphasized the daily sampling frequency, however, PA patterns change within a day, a week, and seasonally. The results of this study show that both PA and symptom reports are rather inconsistent for most women from day to day, and the frequency of vasomotor symptoms tends to vary over time. It will be important for future research to consider sampling activity and symptoms at different timescales to characterize both short-term and long-term variability and individual differences. Given the widely acknowledged underreporting rates of vasomotor symptoms in real life settings [47], it is important to evaluate effects of PA on both subjectively and objectively assessed vasomotor symptoms.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Table 1

Descriptive statistics of the study sample.

| Variable | Mean | SD | Range |
|---|---|---|---|
| Age | 50.4 | 4.9 | 39–62 |
| Height (cm) | 165.7 | 6.1 | 154.5–175.3 |
| Weight (kg) | 65.4 | 11.8 | 46.7–91.0 |
| BMI ($kg/m^2$) | 23.8 | 4.2 | 18.3–33.4 |
| % Total body fat | 30.3 | 7.8 | 14.7–44.2 |
| % Trunk body fat | 27.4 | 9.1 | 11.4–44.6 |
| $VO_2$ peak (ml/kg/min) | 34.0 | 7.8 | 20.4–48.3 |
| FSH (mIU/ml) | 47.2 | 27.5 | 4.4–89.5 |
| LH (mIU/ml) | 27.0 | 13.6 | 3.2–45.7 |
| E1G (ng/ml) | 36.3 | 29.9 | 8.4–111.3 |
| PdG (ug/ml) | 1.6 | 1.6 | 0.3–7.3 |
| Early perimenopausal | 21% | | |
| Late perimenopausal | 38% | | |
| Early postmenopausal | 21% | | |
| Late postmenopausal | 21% | | |
| Education | 75% some college education | | |
| Income | 58% earning above $65,000 | | |
| Marital status | 88% married | | |
| Race/ethnicity | 96% White/Non-Latina | | |

E1G, estrone 1 glucoronide; PdG, pregnenediol glucuronide.

## Table 2

Coefficients representing cross-lagged effects of previous day's physical activity on next day's self-reported hot flash frequency.

| Subject | Total PA counts | Sedentary time | Light intensity | Moderate intensity | Vigorous intensity |
|---|---|---|---|---|---|
| 1 | −0.142 | 0.155 | −0.258 | −0.079 | −0.086 |
| 2 | 0.101 | −0.064 | −0.043 | 0.099 | 0.242* |
| 3 | −0.091 | −0.127 | 0.217 | 0.084 | −0.267* |
| 4 | −0.167 | 0.086 | −0.029 | −0.167 | |
| 5 | 0.217 | −0.290* | 0.190 | 0.315* | |
| 6 | −0.156 | 0.048 | −0.079 | −0.025 | |
| 7 | 0.142 | −0.033 | 0.044 | 0.008 | 0.208 |
| 8 | 0.364* | −0.188 | 0.159 | 0.172 | −0.090 |
| 9 | 0.341* | −0.168 | 0.077 | 0.148 | 0.066 |
| 10 | −0.102 | 0.007 | 0.122 | −0.137 | |
| 11 | −0.037 | 0.042 | −0.093 | 0.086 | −0.315* |
| 12 | 0.073 | −0.107 | 0.055 | −0.006 | 0.104 |
| 13 | −0.068 | 0.011 | 0.051 | −0.069 | −0.133 |
| 14 | 0.031 | 0.071 | −0.142 | 0.010 | 0.148 |
| 15 | −0.063 | −0.312* | 0.245 | 0.126 | 0.065 |
| 16 | 0.112 | −0.065 | 0.136 | −0.025 | 0.107 |
| 17 | −0.030 | −0.320 | 0.243 | 0.667* | −0.199 |
| 18 | 0.282* | −0.157 | 0.013 | 0.268 | −0.128 |
| 19 | 0.011 | 0.011 | −0.061 | 0.072 | |
| 20 | −0.141 | 0.081 | 0.033 | −0.175 | −0.118 |

*Note*: Values represent cross-lagged regression coefficients [$\beta_{PA \rightarrow DHF}$].

*Statistically significant at nominal alpha associated with a nominal $t$-test value of $t_{nom} = 1.5$.