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Exploring the Relationship Between Daily Perceived Stress and Physical Symptoms Across the Menstrual Cycle

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Exploring the Relationship Between Perceived Stress and Physical Symptoms Across the Menstrual Cycle

1. Theoretical Background

Approximately 20–32% of women[1] are affected by the *premenstrual syndrome* (PMS), making it one of the most prevalent syndromes among menstruating individuals between the ages of 20 and 40 (Biggs & Demuth, 2011; Direkvand-Moghadam, 2014). PMS is generally characterized by a variety of emotional, physical, and behavioral symptoms that typically emerge in the days preceding menstruation and subside within a few days after the onset of menstrual bleeding (American Psychiatric Association [APA], 2013). To date, more than 200 different menstrual-related symptoms have already been identified, underscoring the heterogeneity of symptom expression (Lavu et al., 2017). These symptoms range from affective manifestations, such as increased irritability and mood fluctuations, to behavioral symptoms, including difficulties concentrating and changes in appetite (Ryu & Kim, 2015).

Importantly, menstrual-related symptoms do not occur in isolation but tend to influence and amplify one another (Kiesner & Pastore, 2009). For instance, physical symptoms such as abdominal bloating may heighten affective symptoms like anxiety or depressive mood, thereby increasing overall symptom burden (Kiesner & Pastore, 2009). Moreover, menstrual-related symptoms may persist chronically if left untreated and can emerge at any point after menarche (APA, 2013).

Within this complex symptom network, physical symptoms constitute a highly prevalent component of PMS (Quintana-Zinn et al., 2017). Commonly reported physical symptoms include fatigue, nausea, headache, joint and muscle pain, breast tenderness, bloating, and swelling of the extremities (American College of Obstetricians and Gynecologists [ACOG], 2001; APA, 2013; Woods et al., 1998). Because these symptoms are highly prevalent and frequently described as impairing daily functioning and overall quality of life, the present thesis focuses specifically on the etiology and modulation of menstrual-related physical symptoms (Léon-Larios et al., 2024).

[1] References to “women” reflect the terminology of the cited studies, which predominantly included cisgender women. More inclusive terms (e.g., “menstruating individuals”) are used whenever the context allows for gender-inclusive language.

1.1 Terminology and Definitions of Cycle Phases

Because terminology in menstrual cycle research varies considerably across studies and authors, it is helpful to clarify how the relevant cycle-related terms are used in the present thesis (Schmalenberger et al., 2021).

The menstrual cycle is commonly divided into a follicular phase and a luteal phase, with ovulation marking the transition between them. Many studies on menstrual-related symptoms focus primarily on the luteal phase and on the days surrounding the onset of menstruation (Schmalenberger et al., 2021). In this context, the term *premenstrual* is frequently used to describe the final days of the luteal phase immediately preceding menstruation, typically referring to approximately five days before the onset of menstrual bleeding (Schmalenberger et al., 2021). The closely related term *late luteal* is often used interchangeably with premenstrual to refer to the similar time window (Nayman et al., 2023). The *perimenstrual* phase refers to a specific symptom-sensitive window spanning from three days before to two days after the onset of menstruation, during which physical symptoms tend to peak (Kiesner & Pastore, 2010; Nayman et al., 2023; Schmalenberger et al., 2021).

Throughout this thesis, the term *menstrual-related symptoms* is used to refer to symptoms occurring in the days surrounding menstruation, facilitating the synthesis of findings across studies that apply different definitions of cycle-related time windows. When specific empirical studies are discussed, the terminology used by the respective authors is retained to accurately reflect their original phase definitions.

1.2 PMS: Diagnostic Criteria, and Conceptual Distinctions

According to the criteria established by the ACOG, a diagnosis of PMS requires that symptoms occur in at least three consecutive menstrual cycles, begin within the five days before the onset of menstruation, and resolve within four days after menstrual bleeding starts (ACOG, 2001). Moreover, symptoms must significantly interfere with daily functioning (Lustyk et al., 2012; Shulman, 2010*).* To ensure diagnostic accuracy and to capture the cyclic nature of symptom presentation*,* prospective daily symptom ratings must be collected over at least two menstrual cycles (ACOG, 2001). However, a provisional diagnosis may also be made by a clinician before the completion of prospective monitoring (ACOG, 2001; APA, 2013).

There are several related concepts to be distinguished from PMS. For example, approximately 3-8% of women suffer from a severe subtype of PMS, the *Premenstrual Dysphoric Disorder* (PMDD; Dennerstein et al., 2012; Hong et al., 2012; Wittchen et al., 2002). PMDD is recognized in both major diagnostic classification systems, although with some differences in emphasis. The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (APA, 2013) classifies PMDD as a depressive disorder. In contrast, the International Classification of Diseases, 11th Revision (World Health Organization, 2019) lists PMDD as a distinct diagnostic category (GA34.41) within the chapter on diseases of the female genital system. Compared to PMS, a diagnosis of PMDD requires the presence of at least one core affective symptom, accompanied by additional somatic or cognitive symptoms (APA, 2013).

Another concept that should be distinguished from PMS is *premenstrual exacerbation*, which involves the worsening of existing mental or physical health conditions during the luteal phase of the menstrual cycle (Kühner & Nayman, 2021). Examples include mood disorders such as major depression and bipolar disorder (Kühner & Nayman, 2021).

Lastly, *menstrually related mood disorders* describe a group of mood disturbances that are temporally connected to the menstrual cycle, usually appearing during the luteal phase and subsiding shortly after menstruation begins (Eisenlohr-Moul et al., 2016). This umbrella term encompasses a range of severity, including both subclinical mood changes and clinically significant conditions such as PMDD (Eisenlohr-Moul et al., 2016).

1.3 Comorbidities

Various psychological conditions seem to accompany premenstrual disorders. For instance, individuals diagnosed with PMDD or PMS exhibit elevated comorbidity rates with mood disorders (Bengi et al., 2025). Additionally, there is growing evidence of a significant overlap between premenstrual disorders (PMS and PMDD) and post-traumatic stress disorder**,** with research showing that women suffering from post-traumatic stress disorders are more likely to report severe premenstrual symptoms (Eisenlohr-Moul et al., 2016; Perkonigg et al., 2004).

More broadly, PMS has also been associated with increased susceptibility to stress-related disorders and a higher risk of perimenopausal and postpartum depression, indicating a broader vulnerability to hormonally driven emotional

dysregulation throughout the reproductive lifespan (Bencker et al., 2025; Buttner et al., 2013; Korszun et al., 1998; Sidorov et al., 2024).

In addition, there is increasing recognition of the link between premenstrual disorders and suicidality (Osborn et al., 2020; Roy et al., 2025). Individuals experiencing moderate to severe PMS or PMDD have been found to have significantly elevated odds of thinking about and attempting suicide compared to those without PMS or PMDD (Prasad et al., 2021; Roy et al., 2025).

The high comorbidity between PMS and psychological disorders complicates diagnosis and emphasizes the importance of tracking symptoms over time to differentiate menstrual-related symptoms from underlying psychiatric conditions reliably (ACOG, 2001).

1.4 Menstrual Health Burden

Menstrual-related symptoms can have wide-ranging effects on those affected, impacting not only their well-being but also their social relationships in both private and professional settings (Hardy & Hardie, 2017; Victor et al., 2019). For instance, research suggests that women experiencing menstrual-related symptoms are more likely to engage in maladaptive coping strategies, including increased alcohol consumption, tobacco use, and overeating (Isgin-Atici et al., 2018; Strine et al., 2005).

Overall, menstrual-related symptoms are associated with significantly lower scores in mental health, vitality, and emotional well-being, with the impact becoming more severe as these symptoms worsen (Farrokh-Eslamlou et al., 2015; Arbabi et al., 2008; Victor et al., 2019). In addition, women with PMS or PMDD report decreased work productivity during symptomatic phases (Hardy & Hardie, 2017; Heinemann et al., 2010).

Current data from the Austrian menstrual health report (Federal Ministry of Social Affairs, Health, Care, and Consumer Protection [FMSHCC], 2024) underline the broader health burden associated with menstrual-related physical symptoms. According to the report, 36% of menstruating individuals in Austria rate their menstrual pain as severe or very severe (FMSHCC, 2024). Furthermore, physical and psychosocial symptoms were found to significantly affect various areas of life, including sexual activity, work, leisure, and social interactions (FMSHCC, 2024). To manage menstrual-related physical symptoms, more than half of respondents report taking painkillers every month (FMSHCC, 2024).

Given the substantial impacts of menstrual-related symptoms on individuals' daily functioning, understanding the mechanisms underlying these symptoms represents a crucial yet understudied area of menstrual health research (Modzelewski et al., 2024). Building upon this, the following section outlines theoretical perspectives that attempt to explain the etiology of menstrual-related symptoms, with particular attention to the mechanisms underlying the physical symptomatology.

1.5 Etiology of Menstrual-Related Symptoms

To date, various academic fields have sought to explain the origins of menstrual-related symptoms from different viewpoints. Medical research has mainly focused on identifying biological and endocrinological factors (Milewicz & Jedrzejuk, 2006). In contrast, the social sciences have primarily examined the impact of social and cultural influences, while the humanities have explored gendered representations, power dynamics, and political issues (Figert, 2005; Ussher, 2008). Building on these different perspectives, researchers currently believe that menstrual-related symptoms have a *multifactorial origin* (Matsumoto et al., 2007). This involves a mix of hormonal, cultural, neural, dietary, behavioral, and psychosocial factors (Beddig & Kühner, 2017; Bertone-Johnson et al., 2014; Figert, 2005; Kelderhouse & Taylor, 2013). While acknowledging this multifactorial nature, the following sections focus primarily on the endocrinological and psychological mechanisms proposed to underlie the emergence of menstrual-related symptoms.

1.5. 1 Neuroendocrine Etiology of Menstrual-Related Symptoms

Researchers have long suspected that menstrual-related symptoms are associated with fluctuations in sex hormone levels, particularly progesterone and estrogen (Hantsoo & Epperson, 2020; Hoyer et al., 2013). As a result, early scientific models focused on these hormones, their metabolites, and their interactions with neurotransmitter systems and the broader neuroendocrine network (Hantsoo & Epperson, 2020). However, empirical studies have not found consistent differences in absolute hormone levels between individuals with PMS/PMDD and healthy controls (Bloch et al., 1998; Hashemi et al., 2016).

Instead, current research suggests that increased sensitivity to normal hormonal fluctuations, rather than abnormal concentrations, may underlie menstrual-related symptomatology (Hantsoo & Epperson, 2015; Yonkers et al., 2008). A central

focus has been on *allopregnanolone*, a neuroactive metabolite of progesterone that enhances gamma-aminobutyric acid (GABA)ergic transmission and typically exerts calming, anxiolytic effects (Beddig & Kühner, 2017; Rapkin & Akopians, 2012). In the luteal phase, allopregnanolone levels rise with progesterone and fall sharply before menstruation. In individuals with PMS/PMDD, this decline appears to trigger symptoms due to an increased sensitivity to these fluctuations, particularly at the level of $GABA_A$ receptors (Bäckström et al., 2014). This mechanism has primarily been associated with the emergence of affective symptoms such as irritability, anxiety, and mood instability (Bäckström et al., 2014).

Additionally, there is increasing evidence for altered functioning of the key physiological stress system, the hypothalamic–pituitary–adrenal (HPA) axis, in individuals with PMS and particularly PMDD. Several studies report reduced basal cortisol levels, a blunted cortisol awakening response, and diminished acute stress reactivity in affected individuals (Girdler et al., 1998, 2001; Beddig et al., 2019; Hamidovic et al., 2024). Such dysregulation of the HPA axis — including evidence of hyporeactivity — may impair the body's ability to regulate stress and interact with the reproductive system via cortisol-mediated suppression of gonadotropin-releasing hormone (GnRH; Joseph & Whirledge, 2017). However, although dysregulation of the HPA axis may influence GnRH signaling, these effects do not consistently translate into changes in absolute progesterone and estrogen levels (Joseph & Whirledge, 2017).

Taken together, these mechanisms suggest that hormonal withdrawal in the late luteal phase, particularly of allopregnanolone, may interact with blunted stress regulation to create a vulnerability window for menstrual-related symptom emergence.

1.5. 2 Physiological Etiology of Physical Menstrual-Related Symptoms

While affective menstrual-related symptoms are often attributed to fluctuations in neuroactive steroids and GABAergic mechanisms, the origins of physical menstrual-related symptoms – such as bloating, breast tenderness, or general body aches – remain more debated and less theoretically integrated (Weon & Son, 2023).

One possibility debated in the current literature is that the menstrual-related physical symptoms arise secondarily from increased somatic sensitivity during dysphoric mood states (Yonkers et al., 2008). This perspective suggests that physical symptoms may, at least partly, originate from the same neurobiological vulnerability

window underlying affective symptoms (Joseph & Whirledge, 2017; Yonkers et al., 2008). Supporting this notion, trials with selective serotonin reuptake inhibitors, although primarily targeting affective symptoms, have shown modest effects on menstrual-related physical symptoms, such as fatigue or bloating (Majoribanks et al., 2013; Yonkers et al., 2008). Together, these findings point toward overlapping neurobiological pathways underlying menstrual-related affective and physical symptom dimensions (Majoribanks et al., 2013; Yonkers et al., 2008).

Additionally, menstrual-related physical symptoms may arise from direct hormonal effects on peripheral tissues, including the breast, gastrointestinal tract, and brain (Di Leo et al., 2008; Kimbro et al., 2008; Perlman et al., 2005; Yonkers et al., 2008). For example, cyclical breast pain, also known as *mastalgia,* has been linked to altered prolactin regulation (Yonkers et al., 2008). Women affected by mastalgia often exhibit exaggerated luteal-phase prolactin responses, a pattern indicative of functional hyperprolactinemia (Peters, 1992; Yonkers et al., 2008). Pharmacological treatments that reduce prolactin secretion, such as dopamine D2 receptor agonists, have shown efficacy in reducing mastalgia without impacting mood symptoms, suggesting distinct endocrine pathways for affective and physical symptom domains (Bankowski et al., 2003; Ylöstalo et al., 1982).

Overall, this evidence suggests that the neurobiological mechanisms underlying menstrual-related physical symptoms may resemble those implicated in affective symptom expression, yet they likely represent overlapping rather than identical processes (Yonkers et al., 2008).

Importantly, in the context of menstrual-related physical symptom expression, the roles of stress and cortisol have also been discussed (Woods et al., 1998). While HPA axis hyporeactivity has been documented primarily in individuals with PMDD, evidence from broader PMS samples suggests that cortisol dynamics may relate differently to specific physical menstrual-related symptoms (Woods et al., 1998). For example, Woods et al. (1998) found that higher luteal-phase cortisol levels were associated with increased fluid retention, which can manifest as abdominal bloating, swelling of the extremities, breast tenderness, and general body aches (Rosenfeld et al., 2008; Woods et al., 1998).

These findings suggest that cortisol-related processes may serve as a key modulatory factor in the development of menstrual-related physical symptoms. The following sections, therefore, outline how stress, as a broader biopsychological

construct, has been conceptualized and empirically linked to menstrual-related physical symptoms.

1.5. 3 Stress: Conceptualization and Physiological Pathways

Stress is an inherent aspect of human life that, particularly when chronic or excessive, can precipitate adverse outcomes in psychological well-being, physiological health, and cognitive performance (Yaribeygi et al., 2017). While often perceived as negative, stress serves an essential adaptive purpose by enabling the organism to respond effectively to environmental demands (Dhabhar, 2018; Liu et al., 2024). According to Lazarus and Folkman's (1984) *transactional model of stress and coping*, stress arises not from the event itself but from an individual's cognitive appraisal of the situation and the perceived adequacy of available coping resources. Stress is experienced when environmental demands are evaluated as exceeding these resources and threatening personal well-being (Lazarus & Folkman, 1984).

Beyond its psychological dimension, stress also entails a cascade of physiological responses. Activation of the sympathetic nervous system and the HPA axis leads to the release of catecholamines and cortisol, which help mobilize energy and restore homeostasis (McEwen, 2007; Yaribeygi et al., 2017). However, when these systems are chronically activated, they can disrupt immune and inflammatory regulation, heighten pain sensitivity, and increase muscle tension—mechanisms that may contribute not only to general somatic symptoms such as headaches or gastrointestinal discomfort but also to menstrual-related physical symptoms (Hertig et al., 2007; Hwang et al., 2008; Sternbach, 1986).

1.5. 4 Empirical Evidence Linking Stress to Menstrual-Related Physical Symptoms

Empirically, cross-sectional studies have consistently demonstrated that higher perceived stress is associated with more severe menstrual-related physical symptoms (Matsumoto et al., 2019; Singh et al., 2015; Weon & Son, 2023; Yamamoto et al., 2009). For instance, Matsumoto et al. (2019) compared women who reported low versus high levels of current stress and found significantly greater physical premenstrual symptom severity in the high-stress group. This finding aligns with the results of Yamamoto et al. (2009), who reported that female students who experienced menstrual pain also exhibited higher levels of perceived stress than those with no

symptoms. However, due to the retrospective design of such studies, causal inferences remain limited.

One of the few longitudinal studies to directly examine perimenstrual physical symptoms in relation to perceived stress was conducted by Gollenberg et al. (2010). Participants attended four clinical appointments during each of two consecutive menstrual cycles and completed questionnaires assessing perceived stress and the severity of perimenstrual symptoms (Gollenberg et al., 2010). The results showed that individuals who reported high levels of perceived stress during the previous menstrual cycle had a significantly higher risk of experiencing several physical symptoms in the perimenstrual phase (Gollenberg et al., 2010). These findings suggest that cumulative stress exposure may meaningfully contribute to the expression of physical symptoms during the perimenstrual phase (Gollenberg et al., 2010).

More recent work using daily diary designs paints a more detailed picture. Nayman et al. (2023) investigated daily links between perceived stress and clusters of premenstrual symptoms, finding significant effects only for affective symptoms, not physical ones, during the late luteal phase. One likely explanation relates to timing. Physical menstrual-related symptoms usually peak during the perimenstrual phase (Schmalenberger, 2021; Weon & Son, 2023). Although the late luteal window includes the onset of this phase, it also encompasses several days on which physical symptoms are usually less pronounced. As a result, potential stress-related increases in physical symptoms may not have been fully captured.

These findings highlight the importance of examining the entire menstrual cycle in studies of stress and physical symptoms. Including the perimenstrual phase seems crucial for accurately capturing the timing and variability of physical symptom expression. A daily, cycle-spanning approach, therefore, allows stress-related influences to be distinguished from hormonally driven changes and from physiological processes intrinsic to menstruation.

1.6 Purpose of the Study

Although menstrual-related symptoms are well documented, research has largely focused on affective and behavioral symptoms, leaving the determinants of menstrual-related physical symptom severity insufficiently understood (Figert, 2005; Gollenberg et al., 2010; Kollipaka et al., 2013; Namavar Jahromi et al., 2011). While perceived stress has been repeatedly linked to affective symptomatology, its specific

contribution to physical symptoms such as breast tenderness, bloating, and fatigue has received comparatively little empirical attention (Gollenberg et al., 2010; Weon & Son, 2023).

This gap is particularly relevant given the substantial impact of menstrual-related physical symptoms on psychological functioning and daily life, as well as their close interrelation with affective menstrual-related symptoms (Durairaj & Ramamurthi, 2019; Hardy & Hardie, 2017; Kiesner & Pastore, 2009). Although preliminary evidence suggests that stress-reduction interventions (e.g., mindfulness-based approaches or yoga) may alleviate menstrual-related physical symptoms, the theoretical and empirical basis for designing such interventions remains limited due to an incomplete understanding of the association between stress and physical symptoms (Bluth et al., 2015; Vaghela et al., 2019).

Methodologically, existing research examining the link between stress and menstrual-related physical symptoms is constrained by several limitations. Most studies rely on retrospective symptom reports, which are susceptible to recall bias and may lead to overestimation of symptom severity (Chen, 2004; Matsumoto et al., 2021). In addition, much of the evidence stems from laboratory-based designs, which offer limited ecological validity and fail to capture the dynamic, real-world interplay between stress and symptom experience (Junghaenel et al., 2014). Although a small number of longitudinal studies across hormonally validated cycles exist, these investigations typically assess menstrual-related symptoms in general, combining affective and physical components, despite evidence that these symptom subtypes follow distinct temporal patterns across the menstrual cycle (Gollenberg, 2010; Nayman et al., 2023; Schmalenberger et al., 2021).

In addition, inconsistent and often imprecise definitions of menstrual cycle phases further limit the comparability of findings across studies (Schmalenberger et al., 2021). To address this issue, the present study adopts the phase definitions proposed by Schmalenberger et al. (2021), enabling a more precise examination of stress-related physical symptoms across the menstrual cycle.

Finally, much of the existing literature relies on binary sex classifications, thereby excluding trans men and gender-diverse individuals who menstruate (Bigalky et al., 2024; Hyde et al., 2019). The present study addresses this limitation by explicitly including all individuals who menstruate, regardless of gender identity.

The present thesis forms part of a larger ecological momentary assessment (EMA) project investigating psychological and physiological processes across the menstrual cycle. Within this framework, the current analyses focus specifically on the association between perceived stress and the severity of physical symptoms. By examining these variables at the daily level across the menstrual cycle, this thesis contributes to a more fine-grained understanding of how daily fluctuations in stress relate to the onset and intensity of physical symptoms and whether these associations vary across cycle phases. In doing so, it allows for distinguishing between stress as a general somatic burden and stress as a cycle-specific amplifier of physical symptoms, a distinction largely overlooked in prior research. Building on these theoretical and methodological considerations, the following research question and hypotheses are outlined below, reflecting the central focus of this master's thesis.

Research Question

To what extent is daily perceived stress linked to the severity of physical symptoms, and does this association differ between perimenstrual days (i.e., three days before to two days after menstruation onset) and non-perimenstrual days (i.e., all other cycle days)?

Hypotheses

1. On days with higher perceived stress, participants report higher physical symptom severity.
2. Perimenstrual days are associated with higher physical symptom severity than non-perimenstrual days.
3. The positive association between daily stress and symptom severity is stronger on perimenstrual days than on non-perimenstrual days.

2. Method

2.1 Study Design

The present thesis forms part of a larger EMA study investigating psychological and physiological processes across the menstrual cycle. The overarching project employed a prospective, longitudinal design with a mixed within- and between-subjects

structure and received ethical approval from the University of Vienna's Ethics Committee before data collection**.**

Within this broader framework, the present thesis aimed to examine both intra- and inter-individual variation in the association between perceived stress and physical symptoms across the menstrual cycle. Data were collected over two consecutive menstrual cycles, encompassing both a screening phase and a post-assessment phase. However, data from the screening and post-assessment were not included in the final analysis.

The within-subject component focused on changes in perceived stress and physical symptoms across different menstrual cycle phases within the same individual. The between-subject component enabled comparisons across participants, such as examining how differences in stress levels relate to the severity of physical symptoms.

2.2 Eligibility Criteria

To participate in the study, participants had to be between 21 and 45 years old, have basic German language proficiency, and report regular menstrual cycles. Individuals were excluded if they were currently pregnant or breastfeeding, using hormonal contraception or psychotropic medication, or had medical conditions that could affect menstrual or stress-related processes. Substance use and mental health history were also considered during screening. A complete list of inclusion and exclusion criteria is provided in Table B1*,* Appendix B.

2.3 Participants

By August 17, 2025, a total of 233 individuals completed the online screening survey. Based on the inclusion and exclusion criteria, 39 participants were deemed eligible and invited to a baseline appointment with the study team. Of these, 33 completed the first phase of the study, and 27 participants completed both phases, including the post-assessment. One participant was excluded due to non-adherence to study instructions (cannabis use). Detailed information on the reasons for exclusion and the participant flow is provided in Figure C1*,* Appendix C.

The final sample included 26 participants from Austria (70.4%) and Germany (25.9%), all of whom were biologically female and identified as women. Participants were aged between 22 and 39 years (M = 27.62, SD = 4.27). Regarding educational background, 30.8% of participants had completed secondary education (Matura), 3.8%

held a vocational diploma, and 65.4% had obtained a university degree. In terms of occupational status, 61.6% were employed (part-time or full-time), 23.1% were full-time students, and 7.7% were unemployed.

While the present sample of 26 participants provides a rich dataset with repeated daily measurements over an average of 57 days, it may not be sufficiently powered to detect small or medium-sized effects. Based on power simulations for multilevel models with an intraclass correlation (*ICC*) of approximately .40, a sample of approximately 70 participants would be required to detect medium-sized effects (Cohen's d = 0.5) with 80% power (Kleinman, 2021). The current sample size is therefore considered underpowered for reliably detecting medium-to-small effects.

2.4 Study Measures and Materials

To address the research question concerning the association between perceived stress and physical symptom severity across menstrual cycle phases, the study employed psychometrically validated self-report measures to assess daily fluctuations in perceived stress and symptom experiences. Self-report measures were administered repeatedly across two consecutive menstrual cycles and were complemented by assessments of cycle phase and relevant covariates to account for potential confounding influences.

2.4.1 Perceived Stress

Perceived stress was assessed using two complementary self-report measures designed to capture stress at different temporal resolutions. Momentary perceived stress was assessed four times per day using a single-item visual analog scale (VAS), ranging from 0 ("not at all") to 100 ("very much"), in response to the question "How stressed do you feel right now?". Daily perceived stress was collected each evening with the question "How stressed did you feel today?" on the same VAS scale. VAS-based perceived stress measures have demonstrated strong construct validity and sensitivity to both intraindividual and interindividual differences in stress (Lesage et al., 2012).

In the primary analyses, daily perceived stress served as the main predictor of physical symptoms. This decision was motivated by both conceptual and methodological considerations. Specifically, the daily stress rating reflects overall stress exposure across the day and was assessed consistently across both study

phases, thereby maximizing comparability across participants and time. In contrast, momentary stress ratings were collected only during the first part of the study, which would have limited their suitability for longitudinal multilevel modeling (MLM) and reduced comparability across participants.

To address potential systematic differences between the two approaches to stress measurement, momentary stress ratings were additionally aggregated by computing the mean of the four daily momentary assessments and entered as alternative predictors in sensitivity analyses. This approach allowed for an evaluation of whether the pattern of results was robust to the operationalization of perceived stress.

In addition to self-report measures, biological markers of stress and arousal were collected for analyses beyond the scope of the present thesis. Specifically, saliva samples were obtained to quantify cortisol levels and, potentially, alpha-amylase activity. As these biological data will be analyzed only after completion of the broader study project, they were not included in the current analyses.

2.4.2 Menstrual-Related Physical Symptoms

Menstrual-related physical symptoms were measured once daily in the evening using the short form of the PMDD Symptom Diary (Janda et al., 2017). Participants were instructed to rate each symptom with reference to the entire day on a 6-point Likert scale ranging from 0 (“not at all”) to 5 (“extremely”), with higher scores indicating greater symptom severity.

In the present thesis, analyses focused on the physical symptom subscale, which comprises breast-related symptoms (tension, sensitivity, swelling), headaches, joint and muscle pain, perceived weight gain, and weight gain. Example items include “Feeling of tension in the breasts” and “Headaches.”

The short form demonstrated moderate to good internal consistency (Cronbach’s α = .83–.96), convergent validity with the German version of the Premenstrual Symptoms Impact Survey (Wallenstein et al., 2008), and discriminant validity with the Big Five Inventory-10 (Janda et al., 2017).

2.4.3 Cycle Phase

Cycle phase was coded based on the standardized hormone-based definitions proposed by Schmalenberger et al. (2021): mid-luteal (days 17–21), perimenstrual

(days −3 to +2 relative to menses onset), mid-follicular (days −7 to −3 before ovulation or days 4–21 after menses onset), and periovulatory (day of a positive luteinizing hormone [LH] test). This approach ensures temporal precision and comparability across participants.

In the present thesis, cycle phase was additionally dummy-coded, contrasting perimenstrual days (coded 1) with all other cycle phases (coded 0), allowing for hypothesis testing focused specifically on perimenstrual symptom exacerbation.

2.4.4 Control Variables

To account for potential confounding influences on the relationship between perceived stress and menstrual-related physical symptoms, several between-person covariates were included: age, body mass index (BMI), and the presence of a concurrent mental disorder. These covariates were assessed at baseline.

Age was included as a control variable because it has been shown to influence both the severity of menstrual-related symptoms and stress reactivity. Menstrual-related symptoms tend to be more pronounced among younger women (20-35 years old) compared to women over the age of 35 (Freeman et al., 1995; Tavallaee et al., 2011). In addition, younger women report higher levels of subjective stress than older women (Hampel & Petermann, 2017; Hollenstein & Stute, 2014).

BMI was considered because higher BMI has been associated not only with a greater prevalence and severity of PMS overall, but also with increased intensity and frequency of specific physical symptoms, such as swelling of the extremities, back pain, and abdominal cramping (Itriyeva, 2022; Mizgier et al., 2019).

Finally, the presence of a concurrent mental disorder was included due to its well-established association with stress (Lederbogen & Ströhle, 2012). Moreover, Maher et al. (2022) reported that women with elevated mood, anxiety, or stress symptoms exhibited more menstrual irregularities and greater severity of menstrual-related symptoms.

2.5 Procedure

The study procedure comprised a recruitment and screening phase, a baseline assessment, and two consecutive menstrual cycle assessment phases with varying measurement frequencies, followed by a final follow-up session.

2.5.1 Recruitment

Participants were recruited through a multifaceted strategy combining digital and offline channels. Flyers were distributed at various locations, including the university, medical institutions, and within the personal and professional networks of the research team. Additional participants were recruited through informal peer referral, as individuals who had enrolled in the study recommended participation to friends and acquaintances.

Recruitment was also conducted through a study-specific Instagram account, “stress.sex.hormones”, which had been active since June 2024 and regularly shared educational content on stress and menstrual cycle processes. The account launched for recruitment on February 28, 2025, posting information about the study's purpose, namely to investigate the relationship between stress patterns and menstrual symptoms in daily life. Recruitment materials also outlined key inclusion criteria, including age (21-45 years), regularity of menstrual cycles, no current pregnancy, no use of hormonal contraception, and sufficient German language skills. Additionally, participants were informed that, upon completion of the study, they would receive an expense allowance of 120 Euros and individualized feedback on their cycle and symptom patterns. Both flyers and social media posts included a QR code or clickable link directing interested individuals to an online screening questionnaire created with SoSci Survey (Leiner, 2024).

2.5.1 Screening Phase

Upon accessing the screening questionnaire, participants were informed that its purpose was to determine their eligibility for the study, that their responses would be treated confidentially, and that completion would take approximately 5 to 10 minutes. In a separate consent step, participants confirmed their agreement to the processing of their personal data for the study.

The screening procedure followed a structured sequence of questions assessing demographic characteristics, menstrual cycle history (including cycle length, regularity, and dates of the last three menstrual periods), contraceptive use, current and past medical history (including endocrine and chronic conditions), medication use, and diagnosed psychiatric disorders. Additional questions addressed the smartphone model and their willingness to use either their own device or a study-provided device

for daily assessments. The questionnaire was programmed to terminate automatically if any response met predefined exclusion criteria.

In cases of temporary exclusion (e.g., recent discontinuation of hormonal contraception or ongoing breastfeeding), participants were given the option to provide contact information and consent to be approached for future participation. If no exclusion criteria were met, participants were asked to provide their contact details and preferred pronouns. Subsequently, the study team reviewed all screening responses to determine eligibility. Based on this review, participants were either invited to the Department of Psychology at the University of Vienna for a baseline appointment, contacted for clarification regarding specific responses, or informed that they were ineligible to participate. Baseline assessments were scheduled during the follicular phase, a few days after the onset of menses, to ensure participants could begin the study before their estimated ovulation date.

2.5.2 Baseline Appointment

The baseline session, lasting approximately 90 minutes, was conducted in a one-on-one setting with a member of the research team. Upon arrival, participants were welcomed, and the study team introduced themselves. The study process was explained in detail, accompanied by a visual handout illustrating the timeline and the specific tasks involved. Any questions about the study process were addressed at this stage, followed by the provision and signing of written informed consent. All signed consent forms were kept confidential and stored securely in a locked cabinet in the study coordinator's office.

Participants subsequently received detailed, step-by-step instructions on performing ovulation tests, using the study smartphone with the app for daily assessments, and collecting and storing saliva samples. Due to the complexity of these procedures, separate printed manuals were provided for each task, all compiled into a prepared take-home folder. A supervised trial run of saliva sampling was conducted to ensure correct and standardized handling. Additionally, participants received two printed backup schedules for each assessment time point in case of technical difficulties with the app or their smartphone.

Following this, participants completed the baseline questionnaire, which took approximately 15–20 minutes. It included medical, reproductive, and psychiatric histories, information on traumatic experiences, and menstrual cycle characteristics,

as well as questions on PMS symptoms, chronic stress, and emotion regulation. The battery also comprised standardized measures of depressive symptoms and posttraumatic stress symptoms. As part of this assessment, participants generated a personalized, anonymized identification code to allow for secure linkage of their data. In addition, participants aged 40 years or older were screened for menopausal status according to the stages of reproductive aging workshop criteria (Harlow et al., 2012).

After the baseline session, participants were provided with their prepared folder, ovulation tests, pre-labeled saliva collection tubes, and either their assigned study smartphone or detailed instructions for using their personal device. When a study smartphone was issued, a signed receipt was obtained for documentation purposes. The research team confirmed the individual's study start date, which was scheduled four days prior to the estimated ovulation date. The study smartphone was then configured for data collection, either immediately or remotely via a QR code sent via email. Finally, participants were allowed to ask additional questions and confirm their preferred mode of communication (e.g., email or the study app) and their preferred form of address (formal or informal).

2.5.3 Main Study Procedure

Participants took part in the study over two complete menstrual cycles, encompassing two menstrual periods and three ovulatory phases. The study design consisted of two main phases that differed with respect to the frequency of assessment.

Phase one: The first phase began in the follicular phase, approximately four days prior to the estimated ovulation date, and ended two days after a positive LH test in the subsequent follicular phase. During this period, participants completed five assessments per day using their smartphones: immediately upon waking, 30 minutes after waking, at 14:00, at 19:00, and at bedtime. Of these five daily assessments, four assessments (all except the waking survey) measured momentary perceived stress, core affective symptoms of PMDD, and current mood. Participants also reported once per day on physical activity, alcohol consumption, sleep quality, sleep latency, and sleep duration, and completed the full PMDD symptom diary, including physical symptoms.

Saliva samples were collected three times per day (immediately after waking, 30 minutes after waking, and at 19:00), with relevant control variables recorded at the

same time (e.g., nicotine, caffeine, food/drink intake, physical activity, medication use). Menstrual bleeding was assessed during the evening survey; however, participants were instructed to record the onset of menstruation and ovulation separately using dedicated buttons in the app.

Phase two: After completing the first study phase, participants received a QR code and detailed written instructions from the research team to access the second phase within the app. In this phase, daily assessments were reduced to a single bedtime survey to lessen participant burden. This shorter survey continued to assess perceived stress, physical activity, alcohol and nicotine intake, the complete PMDD diary, and menstrual cycle events. Phase two ended 10 days following the onset of the second menstruation.

Participants were allowed to postpone individual assessment windows by up to one hour if they were unable to complete them at the scheduled time. For questions or to report menstrual or ovulatory events, participants were instructed to contact the study team via email or through the in-app messaging function. The study team systematically documented technical issues with the app and regularly forwarded them to the app's support team to ensure timely resolution.

2.5.4 Follow-up Appointment

Participants were scheduled for their closing appointment during the luteal phase of their third cycle (between seven and one day(s) before the expected onset of menstruation). The purpose of this visit was to return study materials, including the study smartphone, any unused LH test strips, and the collected saliva samples. Participants were invited to share feedback and ask any remaining questions regarding their study experience.

At this point, participants either completed the follow-up questionnaire in person or chose to complete it online. The survey assessed chronic stress and emotion regulation, collected feedback for the research team, and allowed participants to register to receive information about the study results upon completion of the project.

The research team subsequently calculated the percentage of completed assessments for each participant. Participants who completed at least 90% of the study assessments received the full compensation of 120 Euros, transferred to their designated bank account. For completion rates below 90%, payment was prorated

accordingly. Within two weeks of study completion, each participant received an individualized cycle and symptom summary via encrypted email.

2.6 Research Team and Study Administration

The study was conducted under the principal investigation of Professor Urs Nater at the Institute for Clinical and Health Psychology, University of Vienna (1010 Vienna, Liebiggasse 5). Study coordination was led by Celine Bencker, MSc, who was responsible for the study's conceptualization, ethical oversight, and supervision of the data collection process, as well as for guiding student assistants and master's students throughout their thesis work.

Baseline and follow-up appointments were held at the study office and conducted by trained members of the research team. All instructions and demonstrations were delivered in accordance with detailed written protocols and checklists to ensure procedural consistency across participants. Interactions with participants were kept neutral and supportive to minimize potential bias.

2.7 Devices and Analytical Tools

Data were collected via the movisensXS smartphone application (Version 2.5.3; movisens GmbH, Germany), which prompted participants at scheduled times throughout the day. Participants who could not use their own device were provided with study smartphones (Nokia 5.4 and Nokia X20; HMD Global, Finland) that were preinstalled with the movisensXS application. Saliva samples were collected using saliva caps (IBL International GmbH, Germany) and stored for later analysis. Ovulation was determined using Clearblue digital ovulation tests (SPD Swiss Precision Diagnostics GmbH, Switzerland), which detect the LH surge in urine with a sensitivity of 40 mIU/mL and a reported reliability of over 99%.

Descriptive analyses were performed using IBM SPSS Statistics (Version 30.0.0.0; IBM Corp., USA), while MLM and missing data analyses were conducted in R (Version 4.5.0; R Foundation for Statistical Computing, Austria).

2.8 Methods of Analysis

Data analysis was conducted using MLM to account for the hierarchical data structure, with repeated daily assessments (Level 1) nested within participants (Level 2). The dependent variable was the composite symptom index, calculated as the daily

mean across all eight physical symptom items (e.g., breast tension, breast sensitivity, breast swelling, headaches, muscle and joint pain, perceived weight gain, and weight gain). The index was computed as:

$$Symptom\_index_{ij} = \frac{1}{8}\sum_{s=1}^{8} PMDD_{s,ij}$$

Where *i* represents the day, *j* the participant, and *s* the individual symptom item.

The primary predictor was daily perceived stress, measured by the daily perceived stress score, which was reported each evening on a 0–100 VAS. To differentiate within-person and between-person effects, stress scores were person-mean-centered. The within-person component reflected day-to-day deviations from each participant's own average stress score and was calculated as:

$$Stress_{wi,ij} = PSS_{ij} - \overline{PSS_j}$$

Where *PSS* represents the perceived stress score.

The between-person component represented each participant's mean level of daily stress across all measurement days and was calculated as:

$$Stress_{bt,j} = \overline{PSS_j}$$

Person-mean centering of daily perceived stress scores enabled separating daily stress fluctuations (within-person variation) from stable individual differences (between-person variation).

Menstrual cycle phase was included as a time-varying covariate and was dummy-coded (0 = non-perimenstrual, 1 = perimenstrual). In line with Schmalenberger et al. (2021), the perimenstrual phase was defined as the window spanning three days before until two days after the onset of menstruation, with all remaining cycle days coded as non-perimenstrual. Thus, the perimenstrual phase effect tested whether symptom severity was systematically higher during the perimenstrual phase relative to all other cycle phases.

Before model estimation, missing data were examined, and Little's test for missing completely at random (MCAR) was performed to assess whether the data

were MCAR (Little, 1988). For the primary analyses, missing data were handled using listwise deletion, as implemented in the lme4 package in R (Bates et al., 2015).

2.8.1 Main Analysis

Analyses proceeded in a stepwise fashion. First, an unconditional (null) model was estimated to partition the variance in physical symptoms into between- and within-person components. Next, a stress-only model was estimated to test the effects of within- and between-person stress on the physical symptom index (Model 1). In a second step, cycle phase and its interaction with daily perceived stress were added to the model (Model 2). Finally, a third model included Level 2 control variables— age, BMI, and psychiatric diagnosis (Model 3). All models were fitted using restricted maximum likelihood in R, and fixed effects are reported as unstandardized regression coefficients (*b*), standard errors (*SE*), Akaike Information Criterion (*AIC*), and *p* values.

2.8.2 Sensitivity Analyses

To examine the robustness of findings, a sensitivity analysis was conducted using multiple imputation. Missing data were handled using predictive mean matching in the mice package in R, generating 20 imputed datasets to achieve stable estimates given the level of missingness (Rubin, 1987; Von Hippel, 2020). Age, BMI, psychiatric diagnosis, and the cycle-phase dummy variable were included as predictors but were not imputed, as they were time-invariant. The multilevel models (Models 1–3) were re-estimated on each imputed dataset using the lmerTest package, and the results were pooled across imputations according to Rubin's Rules using the with() and pool() functions implemented in mice.

In a second step, an alternative operationalization of daily stress was tested by aggregating the four momentary perceived stress scores into a daily mean score. This approach provided a conceptually similar but methodologically distinct measure of daily perceived stress, reflecting the average of momentary stress fluctuations rather than a single end-of-day stress evaluation. To assess the robustness of findings to different stress measurement approaches, this alternative score was entered into all three multilevel models in place of the daily perceived stress score.

3. Results

In this section, descriptive statistics and MLM results are presented to address the research question and hypotheses.

3.1 Descriptive Statistics

Throughout the study, the 26 participants contributed data over a total of 1,499 study days, of which 260 were classified as perimenstrual. On average, participants completed 90.48% of the planned diary entries (*SD* = 8.92).

Table 1 summarizes the descriptive statistics for the daily and participant-level variables. At the participant level, control variables included age, BMI, and current psychiatric diagnosis. Participants were on average 27.62 years (*SD* = 4.27), and the average BMI was 22.07 (*SD* = 2.93). Eight participants (30.8%) reported at least one current psychiatric diagnosis.

The average daily perceived stress score was 35.62 (*SD* = 21.54). To separate day-level variability from stable individual differences, stress was decomposed into within- and between-person components. The between-person stress component (*M* = 35.62, *SD* = 11.07) reflected participants' mean stress levels across the study. In contrast, the within-person stress component (*M* = 0.00, *SD* = 18.41) captured daily deviations from each participant's own mean.

For the individual physical symptom items, which were rated on a 0–5 scale with higher values indicating greater symptom severity, mean values ranged from 0.25 (*SD* = 0.64; joint pain) to 0.58 (*SD* = 0.99; perceived weight gain). The composite physical symptom index, also ranging from 0 to 5, averaged 0.41 (*SD* = 0.53). Across all symptom variables, maximum scores reached the upper limit of the scale, indicating substantial variability in symptom reporting.

Table 1

Descriptive statistics for daily and participant-level variables (N = 26 participants)

Variable	*M*	*SD*	*Min*	*Max*	*N*	%
Participant-level variables						
Age (years)	27.62	4.27	22.00	39.00	26	—
BMI (kg/m^2)	22.07	2.93	18.00	28.00	26	—
Psychiatric diagnosis (yes)					26	30.8
Stress variables						
Daily perceived stress	35.62	21.54	0.00	100.00	1,357	—
Mean stress (between-person)	35.62	11.07	12.08	59.69	26	—
Daily stress (within-person)	0.00	18.41	-44.69	66.04	1,357	—
Physical symptom Variables						
Breast tension	0.36	0.87	0.00	5.00	1,356	—
Breast sensitivity	0.52	1.01	0.00	5.00	1,354	—

Variable	*M*	*SD*	*Min*	*Max*	*N*	%
Breast swelling	0.46	0.99	0.00	5.00	1,354	—
Headache	0.43	0.85	0.00	5.00	1,352	—
Joint pain	0.25	0.64	0.00	4.00	1,354	—
Muscle pain	0.40	0.76	0.00	5.00	1,354	—
Perceived weight gain	0.58	0.99	0.00	5.00	1,354	—
Weight gain	0.30	0.72	0.00	5.00	1,353	—
Physical symptom index	0.41	0.53	0.00	3.12	1,356	—

Note. Physical symptom index = daily mean of the eight symptom items; Daily stress (within-person) = person-mean-centered stress scores; Mean stress (between-person) = participant's average daily stress level across all study days; BMI = body mass index.

3.2 Intercorrelations

As a preliminary step, intercorrelations between the main study variables were examined to provide an overview of their associations and potential shared variance. Table 2 displays the correlations among the key predictors and the dependent variable. Additional correlation matrices, including intercorrelations among all daily symptom items and between-person variables, are provided in Appendix D.

Daily perceived stress was strongly correlated with the within-person stress component (r = .85, p < .001) and moderately correlated with the between-person stress component (r = .52, p < .001). As expected, the within- and between-person stress scores were not correlated ($r \approx 0$), reflecting the effects of person-mean centering.

Correlations between stress and physical symptoms were consistently positive and statistically significant. Specifically, daily perceived stress (r = .15, p < .001) and between-person stress (r = .15, p < .001) showed comparable associations with the

physical symptom index. In addition, the within-person stress component was also significantly correlated with the physical symptom index (r = .09, p < .01).

Table 2

Intercorrelations among key predictors and the dependent variable

Variable	*M*	*SD*	1	2	3	4
1. Daily perceived stress	35.62	21.54	—	.85***	.52***	.15***
2. Daily stress (within-person)	0.00	18.41	.85***	—	.00	.09**
3. Mean stress (between-person)	35.62	11.07	.52***	.00	—	.15***
4. Physical symptom index	0.41	0.53	.15***	.09**	.15***	—

Note. Correlations are Pearson's *r*. * p < .05, ** p < .01, *** p < .001.

3.3 Missing Data Analysis

Missingness rates were evaluated separately for daily-level (Level 1) and participant-level (Level 2) variables. All participant-level (Level 2) covariates — age, BMI, psychiatric diagnosis, and between-person stress — were complete and therefore excluded from the missing-data analysis.

For the daily study variables, only small proportions of missing data were observed. Missingness rates for the daily stress measure (daily stress, within-person), the symptom variables, and the physical symptom index ranged from 9.47% (daily stress, within-person) to 9.81% (headache). These percentages, along with the total count of missing entries, are summarized in Table 3.

A Little's MCAR test conducted on the daily (Level 1) variables indicated no significant deviation from an MCAR pattern, $\chi^2(35) = 12.17$, $p = 1.00$. Accordingly, the primary MLMs were estimated in R using listwise deletion at the observation level. As a sensitivity check, all models were subsequently re-estimated using multiple imputed datasets.

Table 3

Missing Data of key predictors and the dependent variable

Variable	*N*_missing	% missing
Daily perceived stress	142	9.47
Daily stress (within-person)	142	9.47
Breast tension	143	9.54
Breast sensitivity	145	9.67
Breast swelling	145	9.67
Headache	147	9.81
Joint pain	145	9.67
Muscle pain	145	9.67
Perceived weight gain	145	9.67
Weight gain	146	9.74
Physical symptom index	143	9.54

Note. Percentages refer to the proportion of missing observations across all study days (Level 1).

3.4 Verification of Model Prerequisites

To ensure the validity of the analyses, model assumptions were checked for all multilevel models (Models 0–3). For each model, diagnostic checks of residuals and random effects were conducted to assess normality, homoscedasticity, and potential

autocorrelation. Additionally, multicollinearity was examined for all models containing multiple predictors.

Across all models, the diagnostics indicated no violations of the underlying model assumptions. Residuals and random intercepts were approximately normally distributed, and inspection of residuals versus fitted values indicated no heteroscedasticity. Variance inflation factors for all predictors ranged between 1.00 and 1.28, well below the critical threshold of 5, suggesting the absence of problematic multicollinearity. A small lag-1 autocorrelation in the residuals was consistently observed, which is typical for daily diary data, and was therefore considered unproblematic.

Overall, all models met the key criteria of MLM, indicating that the reported parameter estimates are robust and unbiased. Comprehensive visual model diagnostics for all analyses are presented in Appendix E.

3.5 MLM Results

All steps of data preparation, model specification, and assumption checking were performed in R. The corresponding code is attached in Appendix F. The following section presents the results of the MLM analyses. A comprehensive overview of all fixed-effect estimates, including intercepts, *SE*, and *AIC*s, is presented in Table 5.

3.5.1 Null Model (Unconditional Model)

In the unconditional model, the estimated average level of physical symptoms across all participants and days was 0.407 (*SE* = 0.066). Variance decomposition revealed significant variability both between participants (*Var* = 0.110, *SD* = 0.331) and within participants across days (*Var* = 0.173, *SD* = 0.416). The *ICC* was .387, indicating that approximately 38.7% of the variance in physical symptoms was due to between-person differences, while 61.3% reflected within-person fluctuations over time.

As shown in Table 4, the variance components and the *ICC* remained broadly comparable across all subsequent models, indicating a stable random-effects structure. Accordingly, the following sections focus on the fixed effects of the predictors.

Table 4

Variance decomposition and ICCs across models

Model	Var_{bt}	SD_{bt}	Var_{wi}	SD_{wi}	*ICC*
M_0 (null model)	0.110	0.331	0.173	0.416	.387
M_1 (daily stress)	0.109	0.331	0.172	0.414	.389
M_2 (stress x phase)	0.112	0.334	0.133	0.364	.457
M_3 (full model)	0.125	0.353	0.133	0.364	.484

Note. ICC = Intraclass Correlation Coefficient; Var_{bt} = between-person variance; Var_{wi} = within-person variance.

3.5.2 Model 1: Daily Stress Predicting Physical Symptoms

Building on the unconditional model, a random-intercept model was specified to examine the effect of daily stress on physical symptoms, including both within- and between-person stress components. This model structure allows the intercept to vary across individuals, thereby capturing person-specific baseline differences in symptom severity.

As visualized in Figure 1, the within-person effect of stress was statistically significant. On days when participants reported higher stress than their personal average, they also experienced more severe physical symptoms (b = 0.002, p < .001). In contrast, the between-person effect of average stress was not significant (b = 0.006, p = .328), indicating that participants who were generally more stressed across the study did not consistently report higher symptom levels than those who were less stressed.

To examine whether the within-person stress effect varied across participants, a random slope for stress was added to the model. The fixed effect of stress remained significant (b = 0.002, p < .001); however, the random slope variance was estimated to be near zero, resulting in a boundary (singular) fit. This suggests that the strength of the stress-symptom association did not vary meaningfully between participants. Therefore, the simpler random-intercept model was retained as the more parsimonious specification and applied to all subsequent models. The model explained 40.3% of the

total variance in symptom severity (Conditional R^2 = .403), with 2.3% of the variance explained by the fixed effects of daily stress (Marginal R^2 = .023).

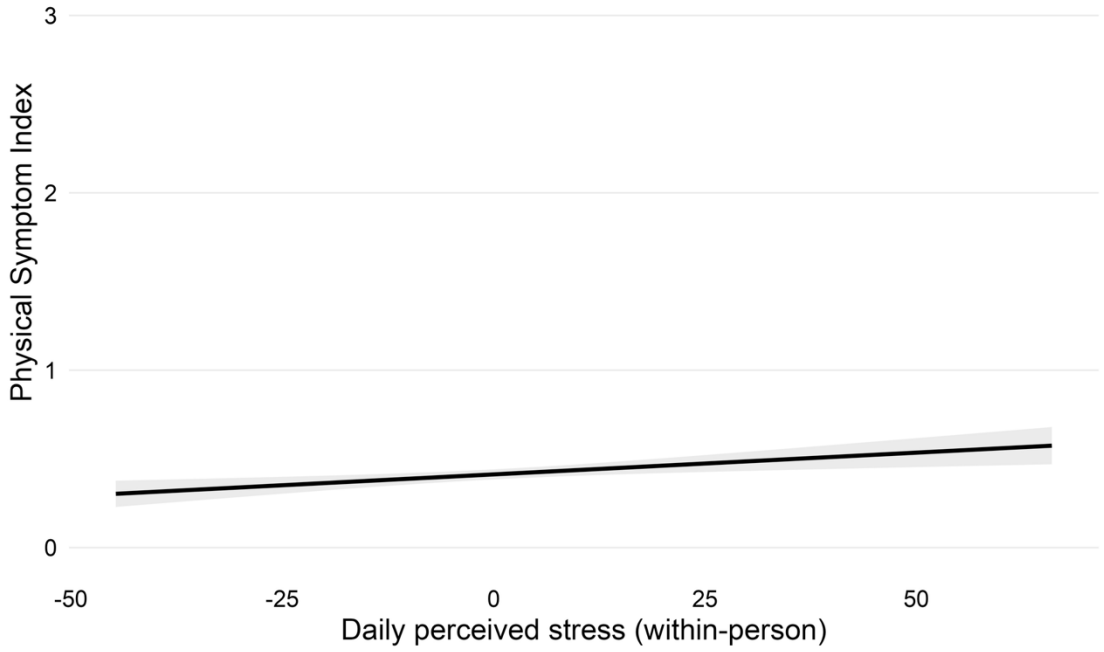

Figure 1. Predicted physical symptoms as a function of within-person stress. The shaded area represents a 95% confidence interval.

3.5.3 Model 2: Cycle Phase as Moderator

When the perimenstrual phase was included as a time-varying predictor, a strong main effect emerged: physical symptoms were significantly higher on perimenstrual days compared to non-perimenstrual days (b = 0.513, p < .001). As shown in Figure 2, the mean physical symptom index across cycle phases shows higher symptom severity during the perimenstrual phase than in the other cycle phases.

In addition, daily stress at the within-person level remained positively associated with physical symptom severity (b = 0.001, p = .042) and the between-person stress effect remained nonsignificant (b = 0.006, p = .322).

To examine whether the stress-symptom association differed between perimenstrual and non-perimenstrual days, the interaction between stress and cycle phase was included in the analysis. The interaction term did not reach conventional significance (b = 0.002, p = .186).

Model comparison based on the *AIC* indicated that this model provided the best fit to the data compared to the alternative models (see Table 5). Overall, the model explained 54.1% of the total variance in physical symptom severity (Conditional R^2 = .541), of which 15.5% was attributable to the fixed effects of stress and cycle phase (Marginal R^2 = .155).

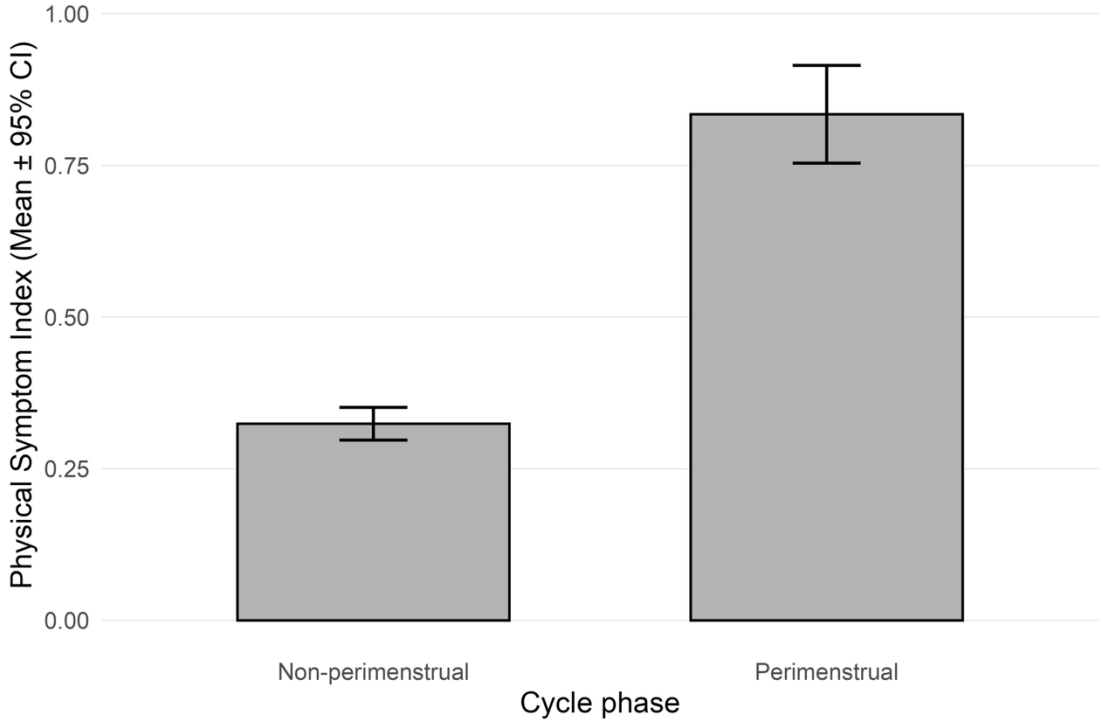

Figure 2. Predicted physical symptoms by cycle phase, with error bars indicating 95% confidence intervals.

3.5.4 Model 3: Control Variables

In the final model, all Level 2 control variables—age, BMI, and psychiatric diagnosis—were added to the existing predictors. The main effects observed in the previous models persisted: physical symptoms were significantly higher on perimenstrual days compared to non-perimenstrual days (b = 0.513, p < .001), and the within-person stress effect (b = 0.001, p = .042) remained significant.

Also, consistent with the previous models, neither the between-person stress effect (b = 0.006, p = .387) nor the stress × cycle phase interaction (b = 0.002, p = .184) reached conventional significance. However, the stress × cycle phase interaction showed a consistent, slightly positive trend, as depicted in Figure 3.

None of the Level 2 control variables—age, BMI, or the presence of a psychiatric diagnosis—were significant predictors of physical symptom severity (*p* values >.05). All in all, the final model explained 56.4% of the variance in symptom severity (Conditional R^2 = .564), with 15.6% explained by the fixed effects of stress, cycle phase, and the control variables (Marginal R^2 = .156).

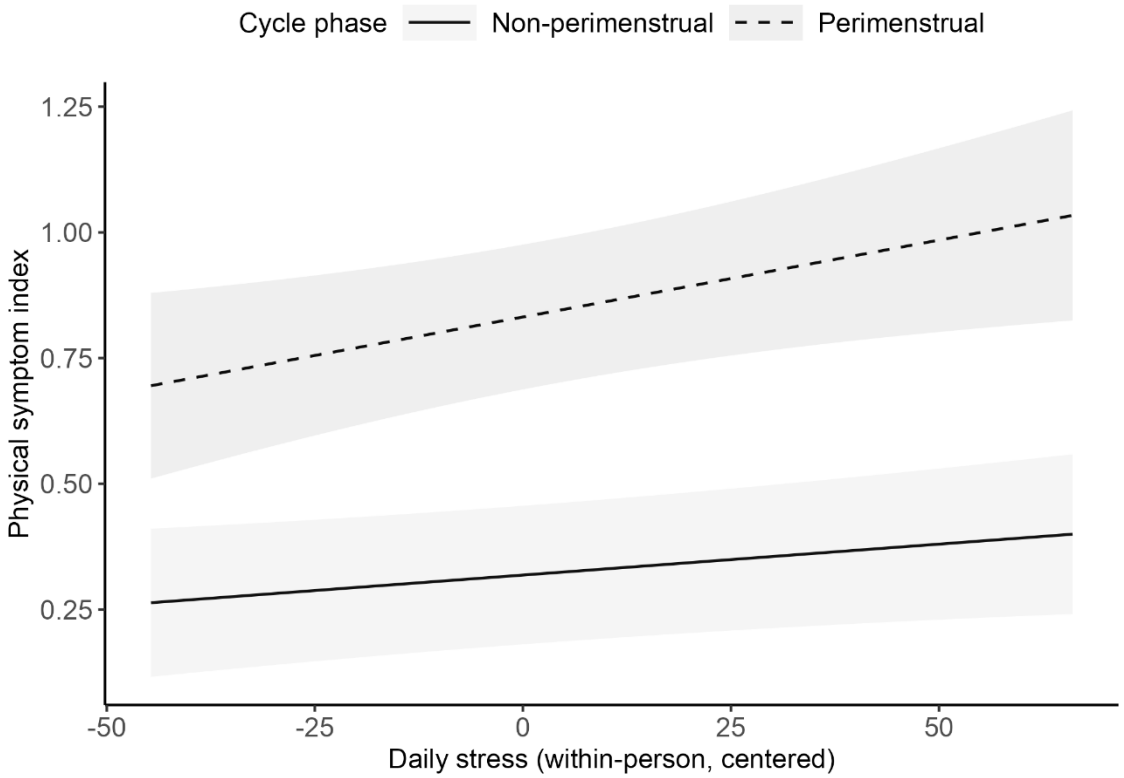

Figure 3. Interaction between within-person stress and cycle phase on the severity of physical symptoms. Lines show predicted values from Model 3; shaded areas indicate 95% confidence intervals. Age, body mass index (BMI), and psychiatric diagnosis were controlled.

Table 5

Multilevel model results predicting physical symptoms.

Predictor	***b***	***SE***	***p***	***AIC***
Model 0 (Null model)				1572.333
Intercept	0.407	0.066	< .001	

Predictor	*b*	*SE*	*p*	*AIC*
Model 1 (Stress only)				1580.257
Intercept	0.195	0.222	.388	
$Stress_{within}$	0.002	0.001	< .001	
$Stress_{between}$	0.006	0.006	.328	
Model 2 (+ Cycle Phase)				1258.374
Intercept	0.101	0.224	.657	
$Stress_{within}$	0.001	0.001	.042	
$Stress_{between}$	0.006	0.006	.322	
Phase (1 = peri)	0.513	0.026	< .001	
$Stress_{within}$ x Phase	0.002	0.001	.186	
Model 3 (+ Controls)				1277.412
Intercept	0.530	0.688	.450	
$Stress_{within}$	0.001	0.001	.042	
$Stress_{between}$	0.006	0.007	.387	
Phase (1 = peri)	0.513	0.026	< .001	
$Stress_{within}$ x Phase	0.002	0.001	.184	
Age	-0.008	0.019	.673	
BMI	-0.010	0.027	.703	
Psychiatric diagnosis	0.108	0.170	.533	

Note. b = unstandardized coefficient; *SE* = standard error; *p* = significance value; *AIC* = Akaike Information Criterion; $Stress_{within}$ = daily stress at the within-person level (person-mean centered); $Stress_{between}$ = average stress at the between-person level (person mean); Phase coded as 0 = non-perimenstrual, 1 = perimenstrual.

3.6 Sensitivity Analyses

3.6.1 Multiple Imputation

To evaluate the robustness of the main results and to address missing data, multiple imputation was performed. Twenty imputed datasets were created, with only the daily perceived stress and the physical premenstrual symptom items imputed, while all other variables were kept fixed. Thus, only missing values were estimated, whereas all observed data remained unchanged. Based on the imputed datasets, the symptom index was recalculated, and the three main models were re-estimated. Results from all imputed models are summarized in Table 6.

Overall, the results obtained from the imputed data essentially replicated the findings of the main analyses. However, unlike the primary models, the within-person stress effect did not reach significance in Models 2 and 3 after imputation (*p* values > .05). In contrast, the main effect of cycle phase remained robust and highly significant across all models (*p* values < .001). The stress × cycle phase interaction, as well as all control variables (age, BMI, psychiatric diagnosis), remained non-significant (*p* values > .05).

As this sensitivity analysis was intended to examine the robustness of the main effects, only the three primary models (Models 1–3) were re-estimated; the null model was not recalculated, as it did not include predictors subject to imputation.

Table 6

Multilevel model results predicting physical symptoms after multiple imputation.

Predictor	***b***	***SE***	***p***	***AIC***
Model 1 (Stress only)				1864.66
Intercept	0.206	0.202	.309	
$Stress_{within}$	0.003	0.001	.001	
$Stress_{between}$	0.006	0.005	.297	
Model 2 (+ Cycle Phase)				497.06
Intercept	0.160	0.282	.569	

Predictor	*b*	*SE*	*p*	*AIC*
$Stress_{within}$	-0.003	0.005	.530	
$Stress_{between}$	0.003	0.007	.712	
Phase (1 = peri)	0.528	0.091	< .001	
$Stress_{within}$ x Phase	0.006	0.005	.201	
Model 3 (+ Controls)				515.19
Intercept	0.421	0.844	.619	
$Stress_{within}$	-0.003	0.005	.529	
$Stress_{between}$	0.002	0.008	.796	
Phase (1 = peri)	0.527	0.091	< .001	
$Stress_{within}$ x Phase	0.006	0.005	.199	
Age	-0.007	0.023	.748	
BMI	-0.003	0.033	.924	
Psychiatric diagnosis	0.115	0.208	.581	

Note. b = unstandardized coefficient; *SE* = standard error; *p* = significance value; *AIC* = Akaike Information Criterion; $Stress_{within}$ = daily stress at the within-person level (person-mean centered); $Stress_{between}$ = average stress at the between-person level (person mean); BMI = body mass index; Phase coded as 0 = non-perimenstrual, 1 = perimenstrual.

3.6.2 Momentary Perceived Stress Measure

As an additional sensitivity analysis, momentary perceived stress was operationalized as the sum of the four perceived momentary stress items instead of the original perceived daily stress score. These momentary stress assessments were collected four times per day during the first study phase and once per day during the second phase. Based on this alternative operationalization, the three main models

were re-estimated, excluding the null model as it did not provide additional explanatory value. All results of this sensitivity analysis are presented in Table 7.

In contrast to the main analyses, neither the within-person nor the between-person stress effects reached significance across any of the re-estimated models (*p* values > .05). By contrast, the main effect of cycle phase remained robust and highly significant throughout all models (*p* values < .001). The stress × phase interaction, as well as all control variables (age, BMI, psychiatric diagnosis), remained non-significant (*p* values > .05).

Table 7

Multilevel model results predicting physical symptoms using an alternative momentary stress measure.

Predictor	***b***	***SE***	***p***	***AIC***
Model 1 (Stress only)				1596.416
Intercept	0.367	0.193	.070	
$Stress_{within}$	0.001	0.001	.571	
$Stress_{between}$	0.001	0.007	.825	
Model 2 (+ Cycle Phase)				1269.99
Intercept	0.272	0.195	.176	
$Stress_{within}$	0.000	0.001	.834	
$Stress_{between}$	0.002	0.007	.811	
Phase (1 = peri)	0.521	0.026	<.001	
$Stress_{within}$ x Phase	0.003	0.002	.176	
Model 3 (+ Controls)				1288.81
Intercept	0.641	0.703	.368	
$Stress_{within}$	0.000	0.001	.836	

Predictor	*b*	*SE*	*p*	*AIC*
$Stress_{between}$	0.002	0.007	.806	
Phase (1 = peri)	0.521	0.026	<.001	
$Stress_{within}$ x Phase	0.003	0.002	.176	
Age	-0.009	0.019	.650	
BMI	-0.008	0.027	.770	
Psychiatric diagnosis	0.134	0.171	.443	

Note. b = unstandardized coefficient; *SE* = standard error; *p* = significance value; *AIC* = Akaike Information Criterion; $Stress_{within}$ = daily stress at the within-person level (person-mean centered); $Stress_{between}$ = average stress at the between-person level (person mean); BMI = body mass index; Phase coded as 0 = non-perimenstrual, 1 = perimenstrual.

4. Discussion

In the following section, the findings of the present thesis are summarized, interpreted, and discussed within the broader body of existing research.

The present thesis aimed to examine the relationship between perceived daily stress and the severity of physical symptoms, and to explore whether this relationship varies across different phases of the menstrual cycle. Building on theoretical and empirical evidence suggesting that perceived stress can influence the expression of menstrual-related physical symptoms (e.g., Gollenberger, 2010; Hantsoo & Epperson, 2020; Lustyk et al., 2006), this thesis was embedded within an EMA study employing a longitudinal design to capture both within- and between-person sources of variation. Over two consecutive menstrual cycles, daily assessments of perceived stress and physical symptoms were collected from 26 participants, enabling a fine-grained and ecologically valid examination of the interplay among stress, menstrual cycle phases, and physical symptomatology.

The analyses revealed an indicative pattern of results that provides insights into how perceived stress and menstrual cycle phases are associated with variations in physical symptom severity.

4.1 Summary and Interpretation of Main Findings

4.1.1 Effect of Stress on Physical Symptom Severity

Consistent with the first hypothesis, the main analysis revealed a statistically significant within-person association between daily perceived stress and physical symptom severity. On days when participants reported higher stress than their individual average, they also tended to experience more severe physical symptoms. Importantly, this effect was not confined to a specific cycle phase but was observed across both perimenstrual and non-perimenstrual phases of the menstrual cycle.

This finding aligns with previous research identifying stress as a relevant contributing factor to a wide range of bodily complaints, including menstrual and abdominal pain, headaches, and joint or muscle discomfort (Hertig et al., 2007; Hwang et al., 2008; Sternbach, 1986). Moreover, the observed influence of stress on physical symptom severity appears theoretically well grounded, as acute stress is known to activate the sympathetic nervous system, heighten pain sensitivity, amplify somatic awareness, and intensify inflammatory processes, mechanisms that may contribute to the occurrence or worsening of physical symptoms independent of menstrual cycle phase (McEwen, 2007; Yaribeygi et al., 2017).

However, results from the sensitivity analyses suggest that the effect of within-person stress on physical symptom severity warrants cautious interpretation. When missing data were handled via multiple imputation, the within-person stress effect reached significance exclusively in the stress-only model, and when an alternative measure of daily stress was applied, the association was no longer significant in any model. These inconsistencies indicate that the observed stress–symptom relationship, while conceptually meaningful, may be sensitive to both the operationalization of stress and the handling of missing data. It is also possible that the relatively small sample size (N = 26) contributed to the attenuation of within-person effects in the imputed datasets. Although multiple imputation can address missing data more effectively than listwise deletion, it may reduce within-person variability and increase *SE*s in small samples, potentially masking subtle associations (McNeish, 2016).

The absence of a significant effect of momentary perceived stress on physical symptom severity further suggests conceptual and methodological differences between momentary and daily perceived stress. While the daily perceived stress index captures an integrated evaluation of perceived stress across the entire day, the momentary assessments reflect transient, context-specific fluctuations that are inherently more variable and less reliable (Mengelkoch et al., 2023). Additionally, the momentary perceived stress index was based on up to four assessments per day, with the first three time points collected only during the first study phase. This uneven data structure may have increased measurement noise and reduced comparability across cycles, thereby weakening the within-person effect. Moreover, momentary assessments are particularly susceptible to missing data during periods of heightened stress, as participants may be less likely to respond during acute stress. In contrast, the evening assessment provides a more stable and comprehensive summary of stress experienced throughout the day. Given these limitations, and because the daily stress assessment provided greater stability and interpretability across both menstrual cycles, it was used as the primary stress measure in the main analyses.

Interestingly, no significant between-person effect of stress levels on physical symptom severity was found. That is, individuals who generally experienced higher stress throughout the study did not report consistently higher physical symptoms than those who were less stressed. This finding stands in contrast to previous cross-sectional studies showing that higher stress levels were associated with more severe menstrual-related symptoms (Matsumoto et al., 2021; Yamamoto et al., 2009). Because cross-sectional designs primarily capture between-person differences in stress, the absence of such an effect in the present study suggests that within-person fluctuations in stress may be more influential in shaping physical symptom severity than stable interindividual differences.

4.1.2 Effect of Menstrual Cycle Phase on Physical Symptom Severity

In line with the second hypothesis, a strong and consistent main effect of cycle phase was found, with physical symptoms being substantially more severe on perimenstrual days compared to non-perimenstrual days.

Model comparison based on the *AIC* further showed that the model introducing cycle phase as a time-varying predictor (Model 2) provided the best overall fit to the data. This pattern was replicated across all analyses, including the sensitivity analyses

based on multiple imputation and the alternative momentary stress measure. The consistently superior model fit indicates that incorporating menstrual cycle phase meaningfully enhances the explanatory power for variations in physical symptom severity and represents a key factor in understanding cyclical changes in physical symptom expression. Notably, in the main analysis, the effect of within-person daily stress remained significant even after controlling for cycle phase, indicating that perceived daily stress contributes to symptom fluctuations beyond phase-related effects.

This finding replicates and extends previous research demonstrating that physical symptoms typically peak during the perimenstrual phase, confirming that this period represents a particularly symptom-sensitive window for menstrual-related physical symptoms (Gollenberg et al., 2010; Schmalenberger et al., 2021). Moreover, the use of validated daily symptom measures, such as the diary developed by Janda et al. (2017), enables a fine-grained, temporally precise assessment of menstrual-related physical symptoms.

4.1.3 Interaction Effect of Cycle Phase and Stress on Symptom Severity

Contrary to expectations outlined in the third hypothesis, the interaction between daily stress and cycle phase did not reach significance. This outcome implies that stress exerts a relatively uniform influence on physical symptom severity throughout the menstrual cycle, rather than amplifying symptom expression specifically in the perimenstrual period. However, there was a positive trend toward a slightly stronger stress-symptom link during the perimenstrual phase compared to non-perimenstrual phases.

One possible explanation for this finding is that previously observed stress–symptom associations during the perimenstrual phase may have been influenced by methodological artifacts or could not be replicated in the current study due to differences in methodology. For instance, many cross-sectional studies relied on retrospective reports of stress and symptom severity, which are vulnerable to recall bias and may lead participants to overestimate symptom levels in hindsight (Gollenberg et al., 2010; Matsumoto et al., 2019; Yamamoto et al., 2009). This interpretation is supported by existing literature demonstrating such biases in retrospective menstrual symptom reporting (Chen, 2004; Matsumoto et al., 2021). In addition to these retrospective distortions, cross-sectional approaches inherently

capture only momentary snapshots rather than dynamic processes (Wang & Chen, 2020). As a result, they provide limited insight into the broader impact of stress on physical symptoms, irrespective of menstrual timing**.** Consequently, previously reported perimenstrual stress effects may partly reflect a more general stress–symptom association, rather than a phase-specific phenomenon, potentially confounding the interpretation of such findings.

Another explanation could be that the effects of stress on physical perimenstrual symptoms do not manifest immediately but occur with a temporal delay. This interpretation would be consistent with the findings of Gollenberg et al. (2010), who observed that stress reported in the previous month predicted greater physical symptoms in the perimenstrual phase of the following cycle.

A further possibility is that the non-significant interaction effect reflects a *ceiling effect* (Wang et al., 2008). Since both cycle phase and stress showed significant main effects on physical symptom severity, the variance explained by their interaction may have been limited. In other words, the perimenstrual phase already accounted for substantial increases in symptom severity, making the additional contribution of stress during this phase statistically indistinguishable from the general effect of stress across all cycle phases.

However, the most plausible explanation is that the interaction between stress and cycle phase exists but is relatively small in magnitude and could not be reliably detected with the present sample size of 26 participants. This interpretation is supported by the observable positive trend, which is consistent with the direction of effects reported in previous studies (Gollenberg et al., 2010; Matsumoto et al., 2019; Yamamoto et al., 2009). The achieved sample size was considerably below the a priori estimated requirement of $N > 70$ for detecting small to medium-sized interaction effects, suggesting that limited statistical power contributed to the non-significant result. Interaction effects in intensive longitudinal designs are generally difficult to detect, as they require both substantial within-person variability and stable between-person contrasts (Bolger & Laurenceau, 2013). In the current dataset, both stress and symptom scores showed relatively high day-to-day variability but low between-person differences, which can further attenuate cross-level interaction effects (Bolger & Laurenceau, 2013). The use of subjective daily reports—although ecologically valid—may also introduce random measurement noise, obscuring subtle, phase-specific associations (Bolger et al., 2003).

4.1.4 Effects of Control Variables

Including control variables such as age, BMI, and psychiatric diagnosis did not meaningfully increase the explained variance or improve overall model fit. The gradual increase in the *ICC* across models—from .39 in the stress-only model to .46 in the model including cycle phase and .48 in the full model—likely reflects minor statistical adjustments rather than substantive contributions of these variables. None of the control variables significantly predicted symptom severity, suggesting that the observed effects of stress and cycle phase are robust and not confounded by demographic or clinical factors.

Interestingly, this finding contrasts with previous research, which has identified several person-level characteristics as predictors of menstrual-related symptom expression. Earlier studies have shown that higher age is typically associated with lower subjective stress levels and less intense menstrual-related symptoms (Hampel & Petermann, 2006; Hollenstein & Stute, 2014), whereas higher BMI has been linked to increased symptom severity and pain intensity (Itriyeva, 2022; Mostafa et al., 2023). Similarly, the presence of a mental disorder has been associated with elevated stress levels and more pronounced menstrual-related symptoms (Lee & Im, 2016; Lederbogen & Stöhle, 2012). The absence of such effects in the present data may reflect the relatively small sample, or it may suggest that within this specific sample, stress and hormonal cycle effects outweigh the influence of demographic and clinical variables.

4.2 Strengths and Limitations

One of the main strengths of this study lies in its intensive longitudinal design and the high temporal resolution of the stress assessments, particularly in the first part of the study. Stress was measured up to four times per day, a method rarely used in previous research (e.g., Nayman et al., 2023). Most prior studies employed cross-sectional designs, and even those using longitudinal approaches typically relied on only one daily assessment (Gollenberg et al., 2010; Lee & Im, 2016; Nayman et al., 2023). To balance scientific rigor with participant feasibility, the evaluation frequency was reduced to one per day in the second phase of the study, ensuring high data quality while minimizing participant burden.

All in all, considerable attention was paid to participant experience throughout the study. Each participant was assigned a consistent study team member as a

personal contact, fostering trust and continuity. This participant-centered approach was reflected in the high compliance rate (>90%) and positive feedback from participants, many of whom described the study as a positive experience and recommended participation to others. Participants were also financially compensated (€120) and received individualized feedback on their cycle patterns. Together, these design characteristics contributed to the study's strong ecological validity, as participants could integrate the study protocol into their everyday lives. Theoretically, the study makes an essential contribution to understanding the role of stress as a modifiable factor influencing menstrual-related symptomatology, thereby offering valuable groundwork for future prevention and intervention strategies aimed at improving the well-being of menstruating individuals.

Despite these strengths, several limitations should be acknowledged. Continuing high-frequency assessments throughout the second study phase would have enabled a more detailed examination of the temporal dynamics between stress and physical symptoms. However, maintaining such an intensive assessment schedule over two complete menstrual cycles would likely have imposed substantial participant burden and reduced compliance. Even with the implemented design, the overall participant burden was relatively high, as participants had to remember to complete daily—and, in the first phase, even multiple—assessments, regardless of how stressful their day was. This continuous reminder of study participation may have been demanding and could have introduced bias. For instance, participants might have been less likely to complete assessments during particularly stressful periods, potentially leading to an underestimation of stress levels. Nevertheless, the overall compliance rate remained high (>90%), suggesting that participants were highly engaged and motivated throughout the study.

Additionally, the relatively small sample size (N = 26) may have limited the analyses' statistical power, potentially obscuring minor interaction effects. However, a further increase in sample size was not feasible within the scope and timeframe of this thesis. The sample was also relatively homogeneous, consisting primarily of women from Austria and Germany, which restricts the cultural generalizability of the findings. Moreover, participants were likely individuals with an above-average interest in menstrual health, introducing a potential selection bias that is particularly relevant given the modest sample size.

Furthermore, since all data were based on self-reports, the results depend on participants' personal perceptions, which can vary depending on individual pain tolerance, body awareness, or symptom sensitivity. Although salivary cortisol samples were collected as an objective measure of physiological stress, this data was not yet available for analysis at the time of this thesis.

Although certain methodological constraints must be acknowledged, this thesis represents a significant contribution within the broader study, offering a solid foundation for investigating the dynamic interplay between stress and physical perimenstrual symptoms in everyday life.

4.3 Future Directions

Building on the current findings, future research should more closely examine the underlying causes of physical menstrual-related symptoms, as these represent a significant health burden and may amplify other symptom domains, such as affective disturbances (FMSHCC, 2024; Kiesner & Pastore, 2009). Particular attention should be given to the perimenstrual phase, a critical time window for physical symptom exacerbation that has often been overlooked in previous research. A deeper understanding of the mechanisms linking stress to physical menstrual-related symptoms is essential for developing targeted interventions aimed at reducing symptom burden and promoting menstrual well-being.

Comparative studies including both individuals with premenstrual disorders (e.g., PMDD or PMS) and non-clinical groups could further illuminate differences in stress reactivity and underlying neurobiological processes. Recent evidence suggests that altered stress regulation—particularly involving $GABA_A$ receptor function—may contribute to heightened symptom sensitivity in individuals with PMS and PMDD (Hantsoo & Epperson, 2020). However, given the current lack of detailed knowledge regarding the etiology of physical menstrual-related symptoms, the present thesis served as a first step in mapping general stress–symptom dynamics before addressing group-specific mechanisms in greater depth.

Because cultural norms shape both perceptions and reporting of menstrual-related symptoms, future studies should aim for larger, more culturally diverse samples to enhance statistical power and generalizability (Figert, 2005). Whenever feasible, subjective self-reports should be complemented by objective physiological

measures (e.g., hormonal or stress biomarkers such as cortisol) to reduce potential bias and strengthen the validity of conclusions.

4.4 Conclusion

In summary, this thesis provides essential insights into the dynamic association between stress and physical symptoms across the menstrual cycle. By employing an intensive longitudinal design over two consecutive menstrual cycles, it captured daily fluctuations in both stress and symptom expression with high ecological validity.

Taken together, the results highlight the menstrual cycle phase as a strong and robust predictor of physical symptom severity, with markedly higher symptoms during the perimenstrual phase across all analyses. In contrast, the association between daily perceived stress and physical symptoms was less consistent. While the main analyses supported a significant within-person effect of daily stress, this relationship did not remain stable when missing data were handled via multiple imputation or when an alternative momentary stress measure was applied. These inconsistencies suggest that the impact of daily stress on physical symptom fluctuations may be relatively small and sensitive to methodological and measurement-related factors. Nevertheless, the theoretical plausibility of this association and its consistency with prior evidence emphasize that stress remains an important variable to consider in models of physical symptom expression.

Future research should replicate these results in more diverse populations and elucidate the underlying mechanisms. Ultimately, this work lays the groundwork for developing targeted interventions to reduce the stress-related burden of physical symptoms and improve the quality of life for menstruating individuals.

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List of Figures

List of Tables

List of Abbreviations

ACOG – American College of Obstetricians and Gynecologists

AIC - Akaike Information Criterion

APA – American Psychiatric Association

B – unstandardized coefficient

BMI – Body Mass Index

EMA – Ecological Momentary Assessment

FMSHCC – Federal Ministry of Social Affairs, Health, Care, and Consumer Protection

GABA – Gamma-Aminobutyric Acid

GnRH – Gonadotropin- Releasing Hormone

HPA – Hypothalamic – Pituitary – Adrenal Axis

LH – Luteinizing Hormone

MCAR – Missing Completely at Random

MLM – Multilevel Modeling

PMDD – Premenstrual Dysphoric Disorder

PMS – Premenstrual Syndrome

PSS – Perceived Stress Score

SE – Standard Error

Appendix A

Abstract

Increased levels of perceived stress have been associated with heightened physical menstrual-related symptoms in previous research. However, few studies have examined this relationship longitudinally. Such designs are essential for capturing temporal dynamics at high resolution and distinguishing phase-specific from general stress effects on physical symptoms.

The present thesis investigated the association between perceived stress and physical symptoms across different menstrual cycle phases using a prospective longitudinal design spanning two complete menstrual cycles. 26 participants provided daily self-reports of stress and physical symptoms. Using multilevel modeling with successive inclusion of predictors and random intercepts, the main analysis indicated that higher daily stress levels were associated with greater physical symptom severity, independent of cycle phase. Physical symptoms were generally more pronounced during the perimenstrual phase, confirming this phase as a key period of physical symptom exacerbation. Although the expected interaction between stress and cycle phase did not reach statistical significance, a positive trend suggested a slightly stronger stress–symptom association during the perimenstrual phase.

Sensitivity analyses using multilevel modeling with multiple imputation and an alternative momentary stress measure revealed that the within-person stress effect was not consistently robust across analytic approaches. These inconsistencies suggest that the observed association between stress and symptom severity may depend on how stress is operationalized and how missing data are handled.

Overall, the findings highlight the perimenstrual phase as a central window of increased vulnerability to physical symptoms and emphasize stress as a theoretically relevant but methodologically sensitive predictor of menstrual-related symptomatology.

Keywords: Stress, menstrual cycle, physical symptoms, perimenstrual phase, longitudinal design, daily assessment

Abstract (German)

Erhöhter subjektiv wahrgenommener Stress wurde in früheren Studien mit einer stärker ausgeprägten physischen Menstruationssymptomatik in Verbindung gebracht. Dennoch haben nur wenige Untersuchungen diesen Zusammenhang longitudinal untersucht. Solche Studiendesigns sind jedoch entscheidend, um zeitliche Dynamiken mit hoher Auflösung abzubilden und phasenspezifische von allgemeinen Stresseffekten hinsichtlich körperlicher Symptome zu unterscheiden.

Die vorliegende Masterarbeit untersuchte den Zusammenhang zwischen subjektiv wahrgenommenem Stress und körperlichen Symptomen in unterschiedlichen Zyklusphasen anhand einer prospektiven Längsschnittstudie über zwei vollständige Menstruationszyklen mit 26 Teilnehmerinnen. In der Hauptanalyse zeigte sich, unter Verwendung von Mehrebenenmodellen mit sukzessiver Aufnahme der Prädiktoren, dass höhere tägliche Stresswerte mit einer stärkeren Ausprägung physischer Symptome einhergingen, unabhängig von der jeweiligen Zyklusphase. Zudem traten in der perimenstruellen Phase insgesamt höhere körperliche Symptomwerte auf als in anderen Zyklusphasen. Der erwartete Interaktionseffekt zwischen Stress und Zyklusphase war zwar nicht signifikant, zeigte jedoch einen positiven Trend, der auf eine leicht verstärkte Stress-Symptom-Assoziation in der perimenstruellen Phase hinweist.

Sensitivitätsanalysen auf Basis von Mehrebenenmodellen mit multipler Imputation und einem alternativen Stressmaß ergaben, dass der innerhalb der Personen beobachtete Stresseffekt nicht in allen Analysen stabil blieb. Dies deutet darauf hin, dass die Stärke des Zusammenhangs zwischen Stress und Symptomen von der jeweiligen Stressmessung sowie vom Umgang mit fehlenden Daten beeinflusst werden kann. Insgesamt heben die Befunde die perimenstruelle Phase als zentrale Phase erhöhter Vulnerabilität für physische Symptome hervor und unterstreichen Stress als theoretisch bedeutsamen, zugleich aber methodisch sensiblen Prädiktor menstruationsbezogener Symptomatik.

Schlagwörter: Stress, Menstruationszyklus, körperliche Symptome, perimenstruelle Phase, Längsschnittdesign, tägliche Erhebung

Appendix B

Inclusion and Exclusion Criteria

Table B1

Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Age between 21-45 years	Pregnancy or breastfeeding in the past 3 months
Regular menstrual cycles (variability in menstrual onset ≤ 5 days)	Use of hormonal contraception in the past 3 months
Working knowledge of German	Intake of psychotropic medication
BMI between 17 and 34.99	Severe somatic disease (e.g., cancer, Crohn's disease, etc.)
	Endocrine disorders (e.g., Cushing's syndrome, Addison's disease)
	Gynecological disorders affecting the menstrual cycle (e.g., endometriosis, PCOS)
	Heavy alcohol use in the past three months (> 8 drinks/week)
	Bipolar disorder or schizophrenia
	Substance-induced disorders (unless in remission for ≥ 3 months)
	Illicit drug use (including cannabis) in the past 14 days; unwillingness to abstain during the study
	Engagement in shift work

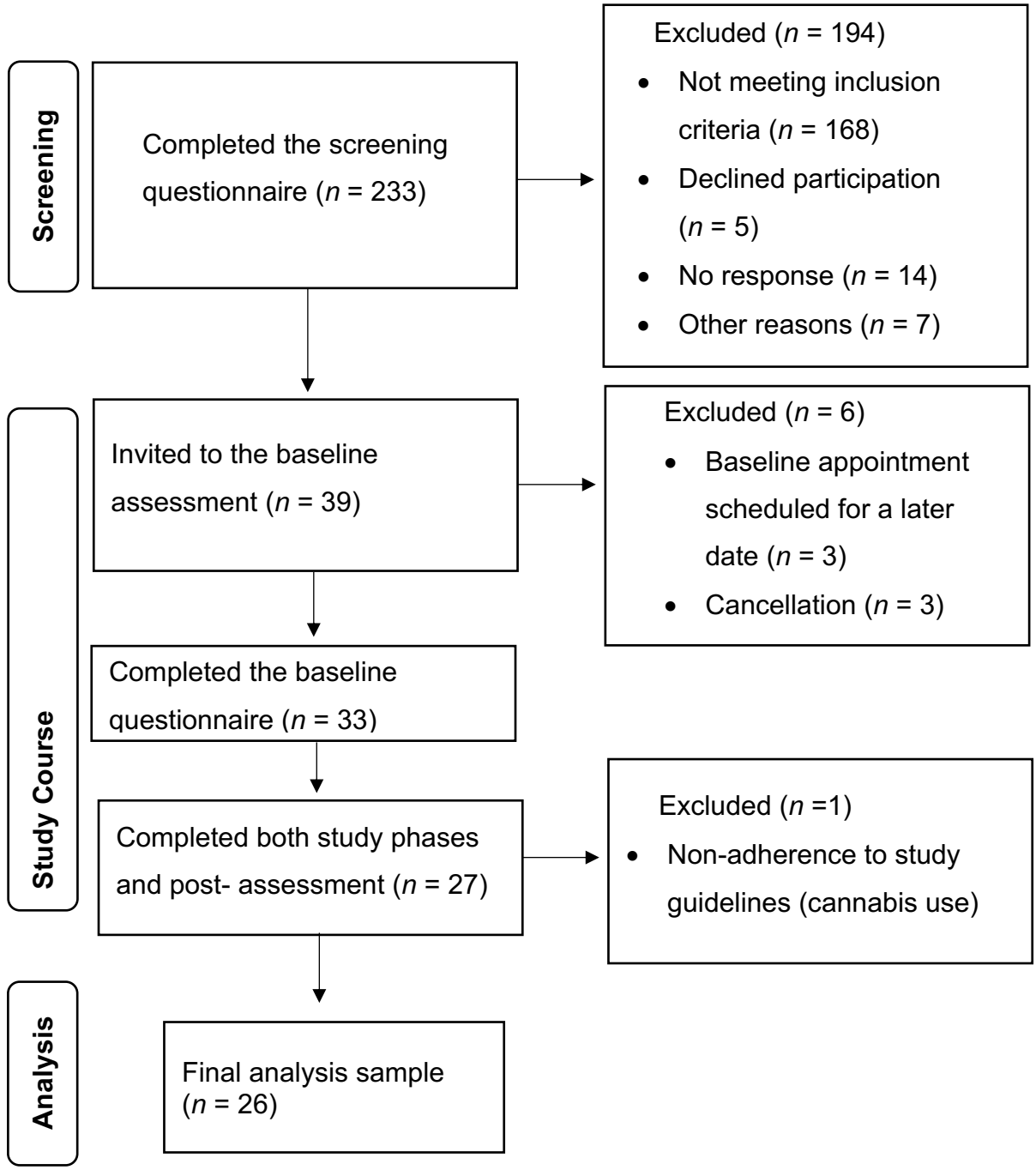
Note. PCOS = polycystic ovarian syndrome

Appendix C

Participant Flow Diagram

Figure C1

Participant Flow Diagram



Appendix D
Intercorrelations

Table D1

Intercorrelations among daily (Level 1) variables (lower triangle), with means and standard deviations.

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11
1. PSS Daily	35.62	21.54	—										
2. Daily stress (within-person)	0.00	18.41	.85***	—									
3. Physical symptom index	0.41	0.53	.15***	.09**	—								
4. Breast tension	0.36	0.87	.06*	.08**	.74***	—							
5. Breast sensitivity	0.52	1.01	.06*	.05*	.74***	.81***	—						
6. Breast swelling	0.46	0.99	.06*	.05	.81***	.82***	.8***	—					

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11
7. Headache	0.43	0.85	.13***	.09**	.37***	.05	.03	.07**	—				
8. Joint pain	0.25	0.64	.13***	.05	.41***	.14***	.13***	.1***	.17***	—			
9. Muscle pain	0.40	0.76	.11***	.05	.47***	.12***	.09**	.12***	.27***	.45***	—		
10. Perceived weight gain	0.58	0.99	.12***	.04	.68***	.28***	.29***	.42***	.15***	.15***	.26***	—	
11. Weight gain	0.30	0.72	.11***	.01	.62***	.24***	.24***	.37***	.13***	.15***	.22***	.72***	—

Note. Correlations are Pearson's *r*. * $p < .05$, ** $p < .01$, *** $p < .001$.

Table D2

Intercorrelations among between-person (Level 2) variables (lower triangle), with means and standard deviations.

Variable	*M*	*SD*	1	2	3	4	5
1. Mean stress (between-person)	35.46	11.22	—				

Variable	***M***	***SD***	**1**	**2**	**3**	**4**	**5**
2. Mean physical symptom index	0.41	0.34	.2	—			
3. Age (years)	27.76	4.29	.02	-.11	—		
4. BMI (kg/m^2)	22.12	2.98	.12	-.07	.34	—	
5. Psychiatric Comorbidity (0/1)	0.31	0.47	.17	.12	.37	.31	—

Note. BMI = body mass index; Correlations are Pearson's *r*. * $p < .05$, ** $p < .01$, *** $p < .001$.

Appendix E

Verification of Model Prerequisites

Figure E1

Histogram of standardized residuals (Model 0)

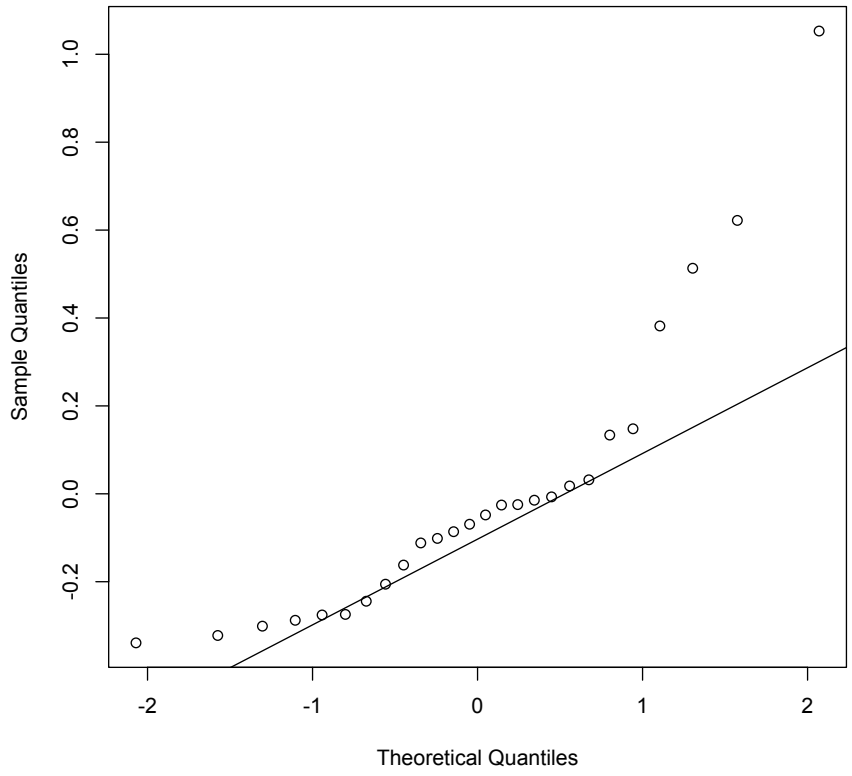


Figure E2

Q-Q plot of residuals (Model 0)

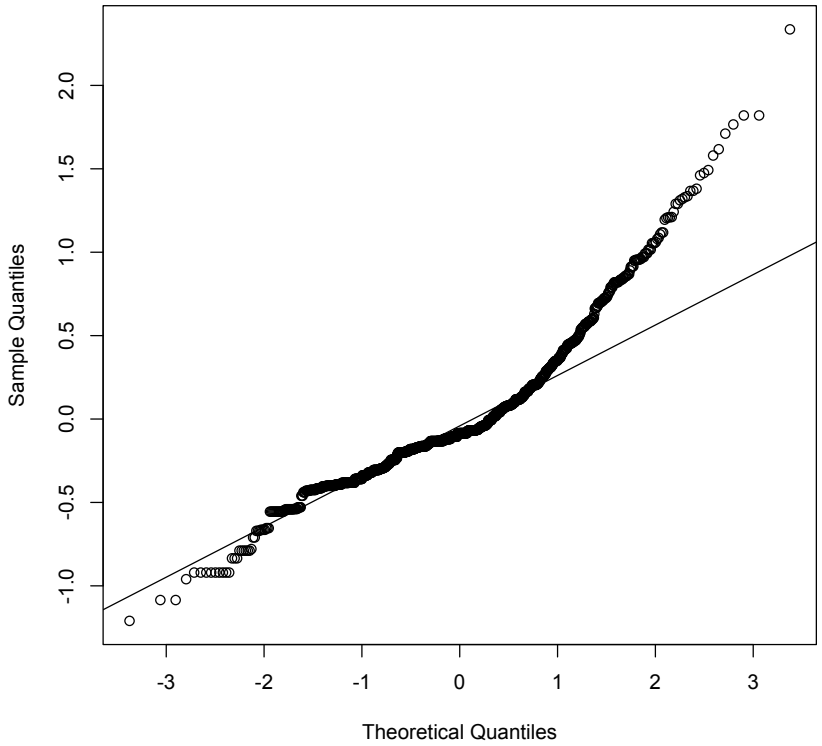


Figure E3

Residuals vs. fitted values - Homoscedasticity (Model 0)

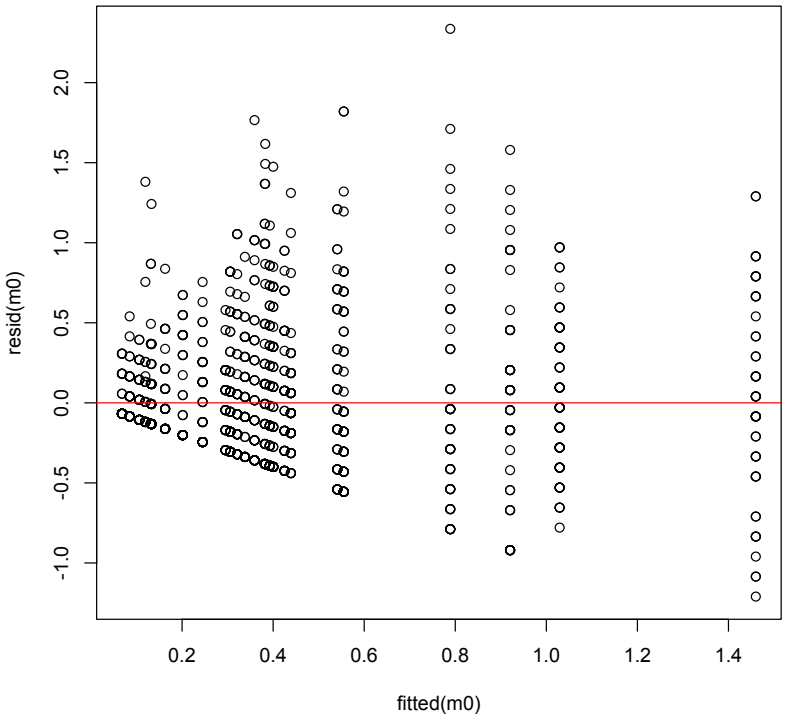


Figure E4

Autocorrelation Function of Residuals – Independence Test (Model 0)

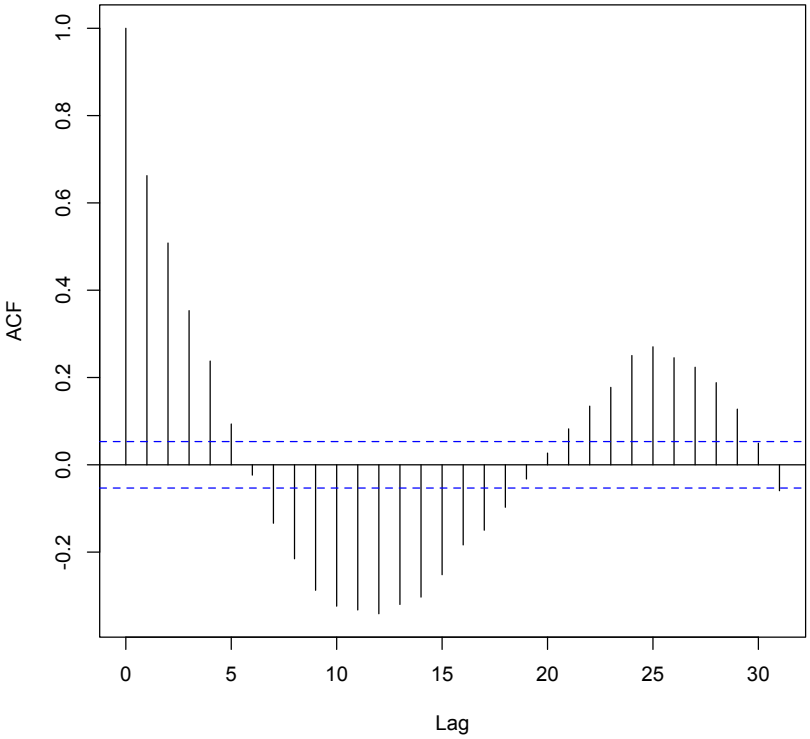


Figure E5

Histogram of standardized residuals (Model 1)

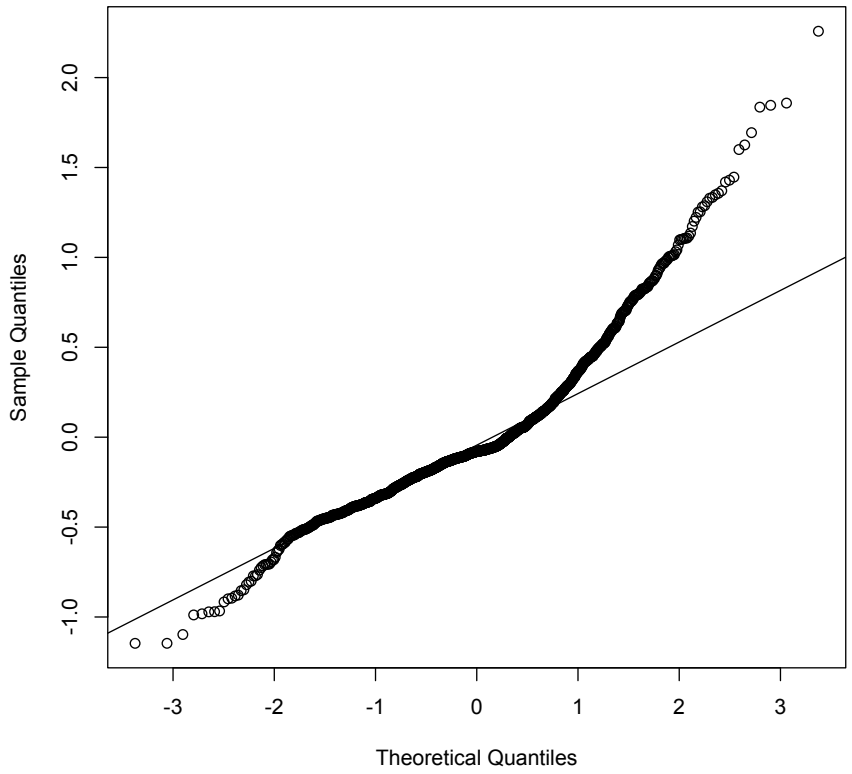


Figure E6

Q-Q plot of residuals (Model 1)

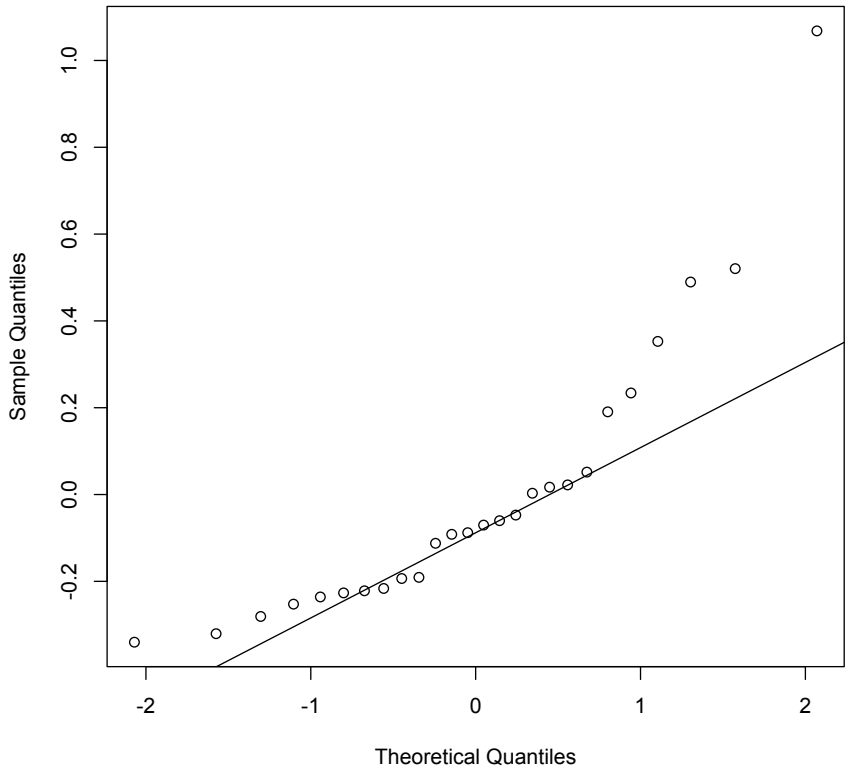


Figure E7

Residuals vs. fitted values - Homoscedasticity (Model 1)

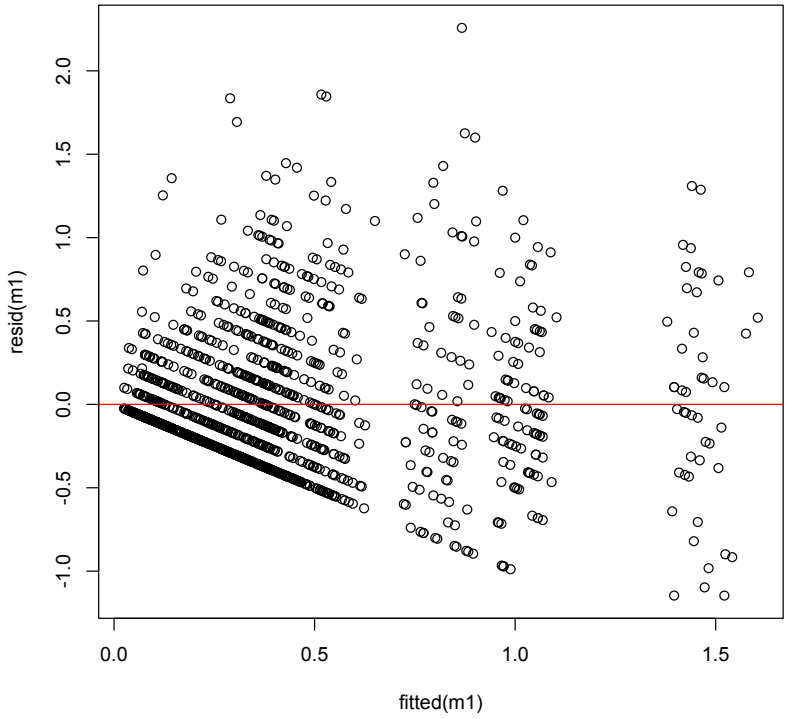


Figure E8

Autocorrelation Function of Residuals – Independence Test (Model 1)

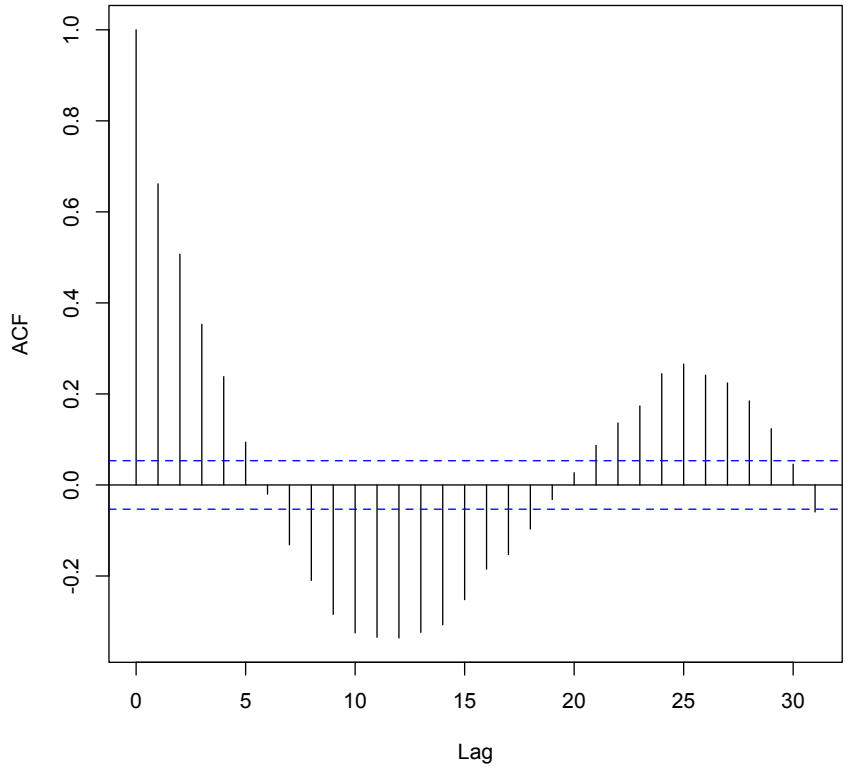


Figure E9

Histogram of standardized residuals (Model 2)

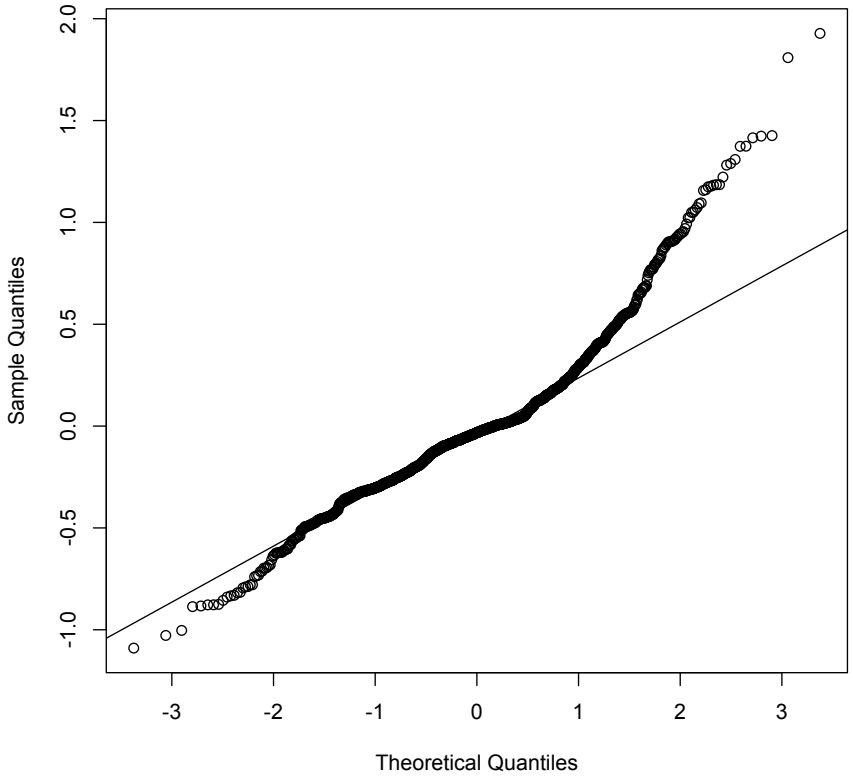


Figure E10

Q-Q plot of residuals (Model 2)

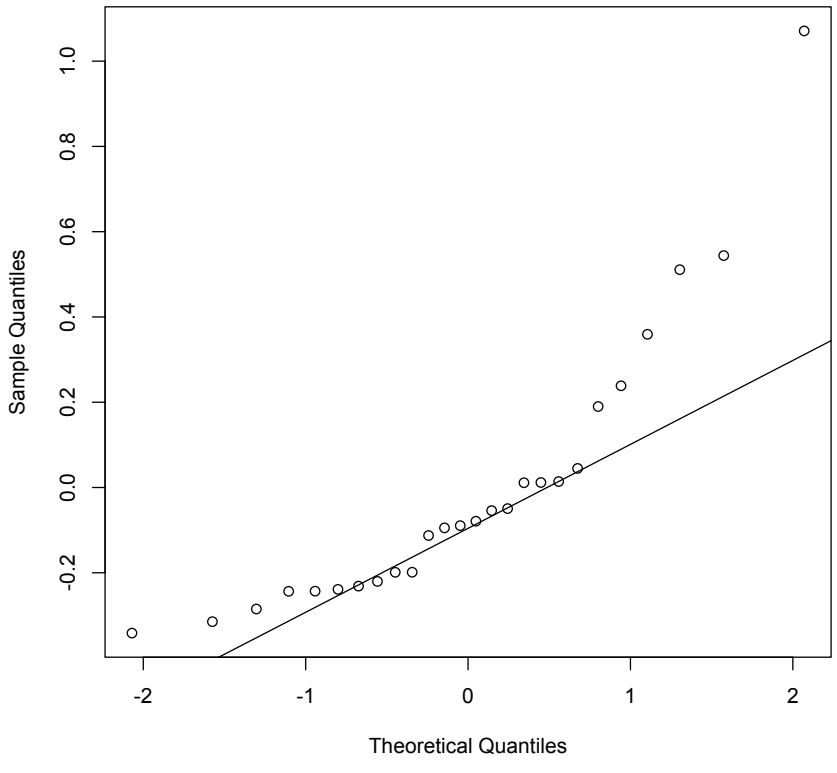


Figure E11

Residuals vs. fitted values – Homoscedasticity (Model 2)

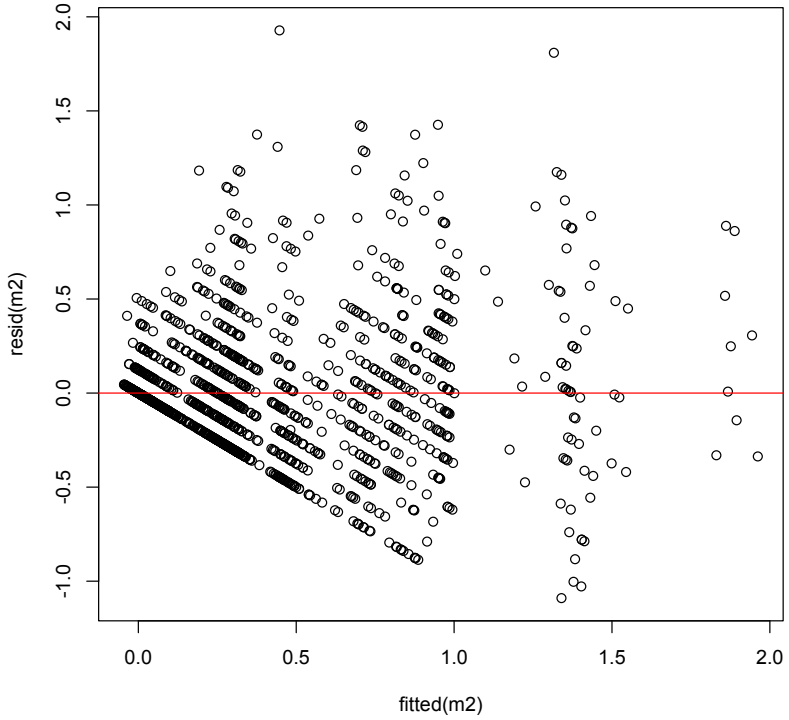


Figure E12

Autocorrelation Function of Residuals – Independence Test (Model 2)

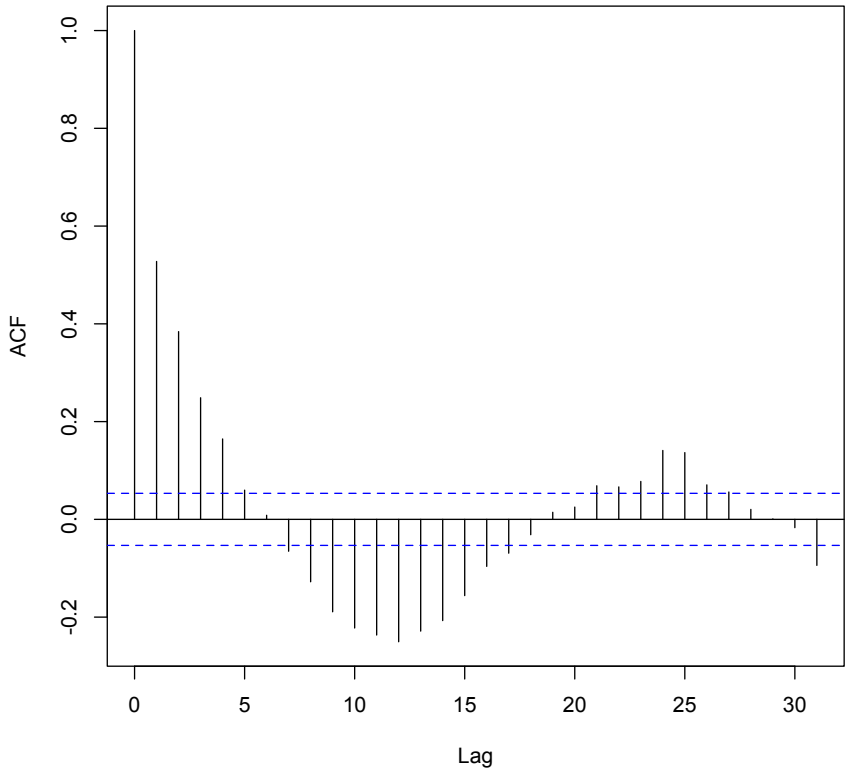


Figure E13

Histogram of standardized residuals (Model 3)

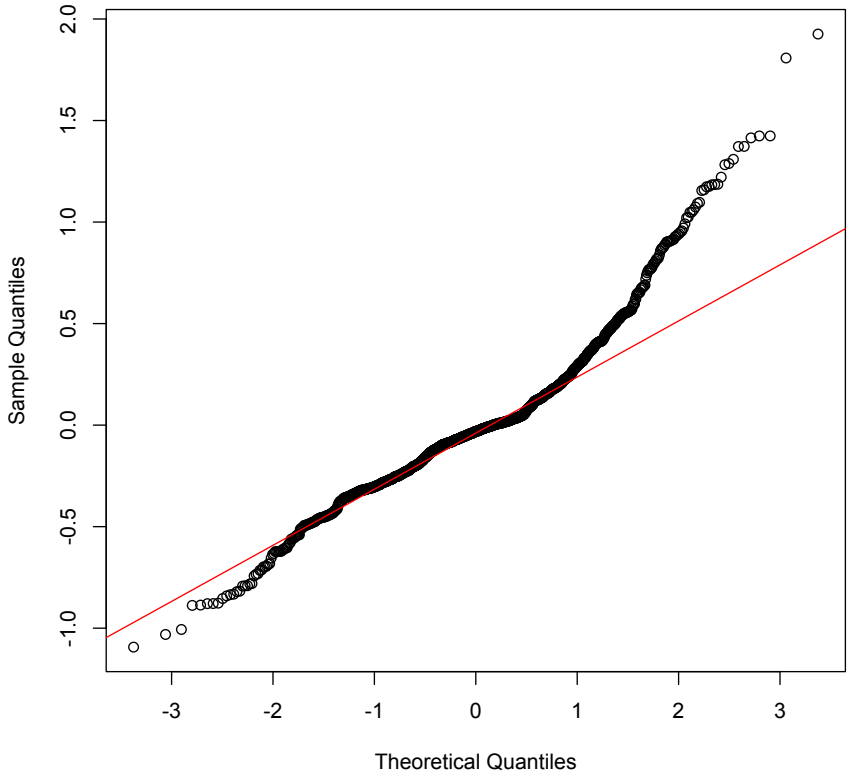


Figure E14

Q-Q plot of residuals (Model 3)

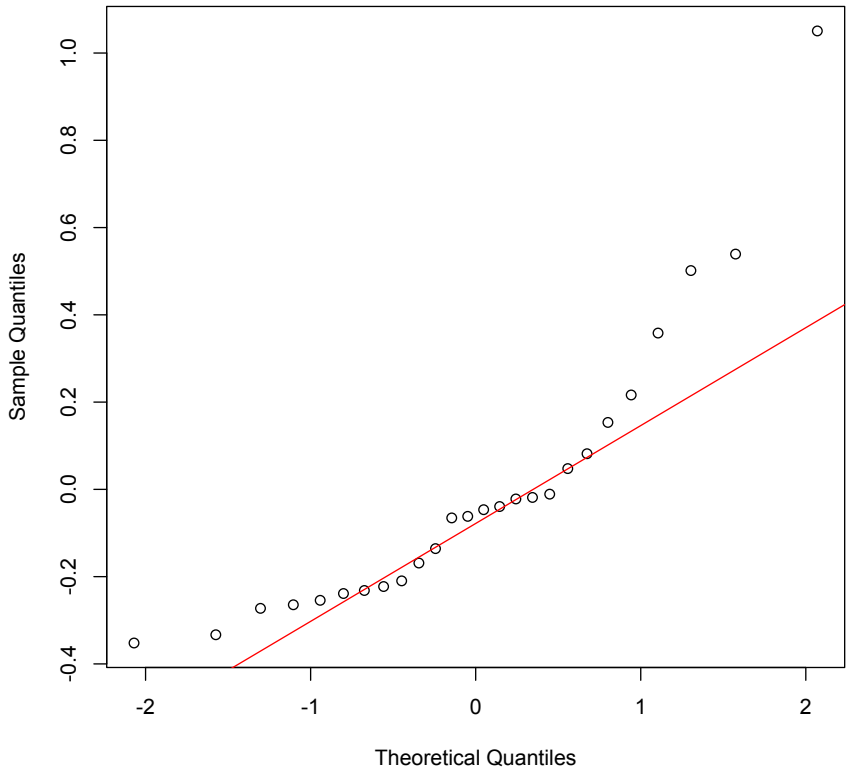


Figure E15

Residuals vs. Fitted Values – Homoscedasticity (Model 3)

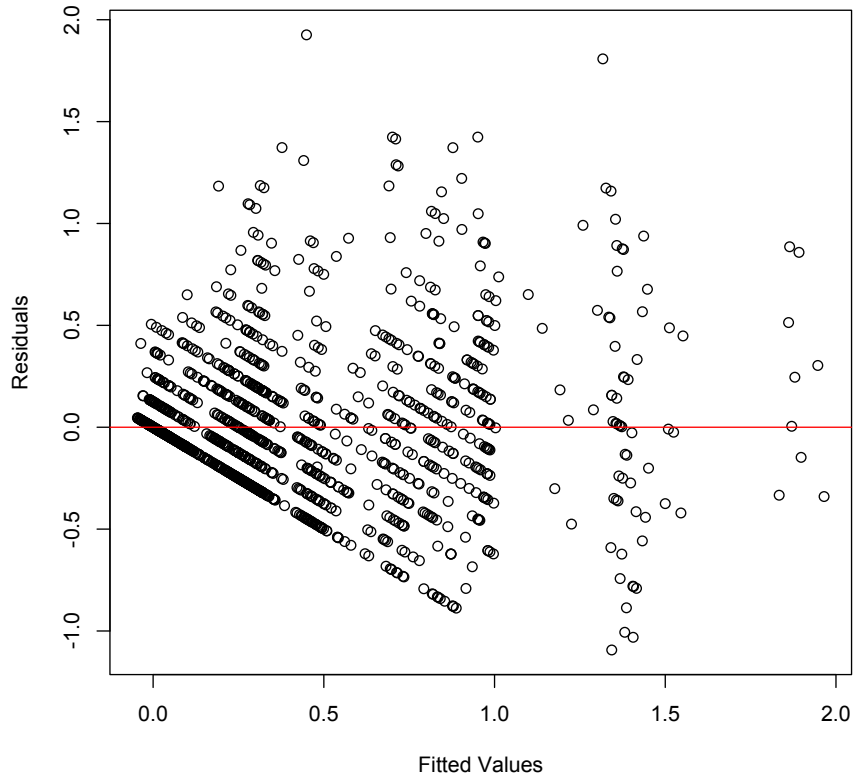
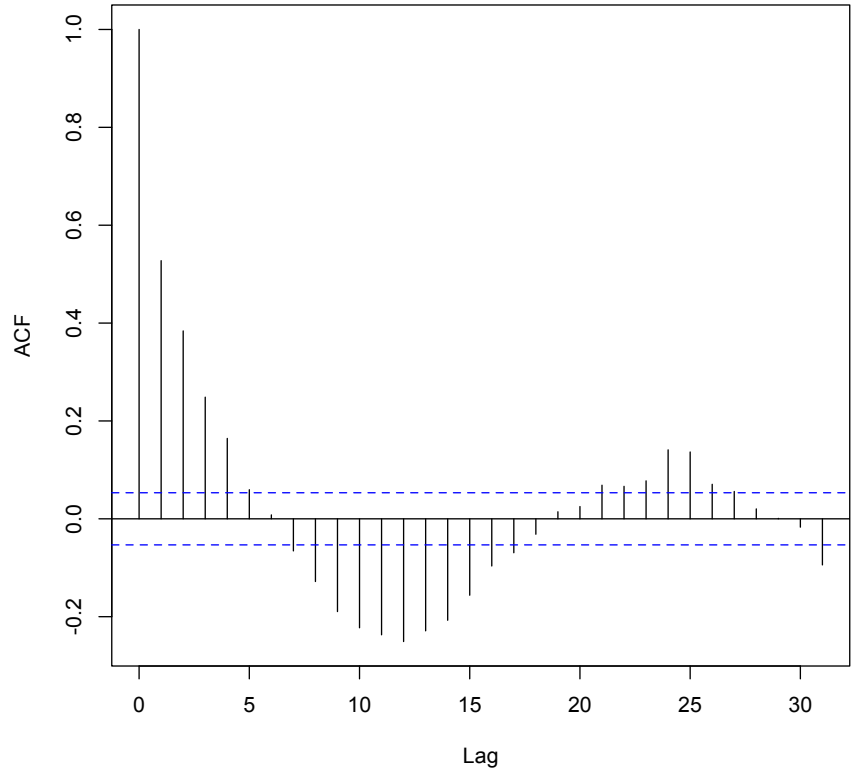


Figure E16

Autocorrelation Function of Residuals – Independence Test (Model 3)



Appendix F

R Code

The following R code was used for data preparation, multilevel modeling, and sensitivity analyses.

```
### Load required packages
library(lme4)
library(lmerTest)
library(mice)
library(dplyr)
library(tidyr)
library(readxl)
library(broom.mixed)
library(performance)
library(naniar)

################################################################################
# 1. Data Preparation – Primary Dataset
################################################################################

# Load dataset
file_path <- file.choose()
data <- read_excel(file_path)

# Recode all "99" and text-based missing values as NA
data[data == 99] <- NA

################################################################################
# 2. Variable Preparation & Missing Data Analysis
################################################################################

# Compute physical symptom index (mean across PMDD_21–PMDD_28)
data$symptom_index <- rowMeans(data[, c("pmdd_21_breasttension",
                                        "pmdd_22_breast_sensitivity",
                                        "pmdd_23_breast_swelling",
                                        "pmdd_24_headache",
                                        "pmdd_25_joint_pain",
                                        "pmdd_26_muscle_pain",
                                        "pmdd_27_perceived_weight_gain",
                                        "pmdd_28_weight_gain")],
                               na.rm = TRUE)

# Person-mean centering of daily stress
data <- data %>%
  group_by(Participant) %>%
  mutate(pss_bt = mean(pss_totalday, na.rm = TRUE),
         pss_wi = pss_totalday - pss_bt)

# Clean and recode cycle phase
data$`Cycle Phase` <- tolower(trimws(data$`Cycle Phase`))
data$`Cycle Phase`[data$`Cycle Phase` == "" | data$`Cycle Phase` == " "] <- NA
data$phase_bin <- ifelse(data$`Cycle Phase` == "perimenstrual", 1, 0)
data$phase_bin[is.na(data$phase_bin)] <- 0

# Convert participant to factor
data$Participant <- as.factor(trimws(data$Participant))
```

```
# Fill Level-2 variables (constant within participants)
data <- data %>%
  group_by(Participant) %>%
  tidyr::fill(Age, BMI, mental_health_diagnosis, .direction = "updown")

# Verify constancy of Level-2 variables
check_constants <- data %>%
  group_by(Participant) %>%
  summarise(
    age_var = var(Age, na.rm = TRUE),
    bmi_var = var(BMI, na.rm = TRUE),
    diag_var = var(as.numeric(mental_health_diagnosis), na.rm = TRUE)
  )
print(check_constants)


Missing Data Overview
# Variables of interest for missingness inspection
vars_missing <- c("pss_totalday", "pss_wi", "symptom_index",
                  "pmdd_21_breasttension", "pmdd_22_breast_sensitivity",
                  "pmdd_23_breast_swelling", "pmdd_24_headache",
                  "pmdd_25_joint_pain", "pmdd_26_muscle_pain",
                  "pmdd_27_perceived_weight_gain", "pmdd_28_weight_gain")

# Calculate absolute and percentage of missing data
missing_counts <- colSums(is.na(data[vars_missing]))
missing_percents <- round(colMeans(is.na(data[vars_missing])) * 100, 2)

# Combine into summary table
missing_summary <- data.frame(
  Variable = vars_missing,
  Missing_Count = missing_counts,
  Missing_Percent = missing_percents
)

# Print missing data summary
cat("\nMissing Values per Variable:\n")
print(missing_summary)

# Overall proportion of missing data
total_missing <- mean(is.na(data[vars_missing]))
cat("\nOverall proportion of missing data across all variables:",
    round(total_missing * 100, 2), "%\n")

Little's MCAR Test:
mcar_test <- naniar::mcar_test(data[vars_missing])
print(mcar_test)

################################################################################
# 3. Primary Multilevel Models
################################################################################

# Model 0: Null model
m0 <- lmer(symptom_index ~ 1 + (1 | Participant), data = data)

# Model 1: Stress only
m1 <- lmer(symptom_index ~ pss_wi + pss_bt + (1 | Participant), data = data)

# Model 2: Add Cycle Phase (and interaction)
m2 <- lmer(symptom_index ~ pss_wi * phase_bin + pss_bt + (1 | Participant), data =
data)
```

```
# Model 3: Add control variables
m3 <- lmer(symptom_index ~ pss_wi * phase_bin + pss_bt +
             Age + BMI + mental_health_diagnosis + (1 | Participant),
           data = data)

# Summaries
summary(m0)
summary(m1)
summary(m2)
summary(m3)

################################################################################
# 4. Model Fit: ICC, R² and AIC
################################################################################

# ICCs
icc_m0 <- performance::icc(m0)
icc_m1 <- performance::icc(m1)
icc_m2 <- performance::icc(m2)
icc_m3 <- performance::icc(m3)

cat("\n--- Intraclass Correlations (ICCs) ---\n")
print(icc_m0)
print(icc_m1)
print(icc_m2)
print(icc_m3)

# R² (Nakagawa & Schielzeth, 2013)
print(performance::r2_nakagawa(m0))
print(performance::r2_nakagawa(m1))
print(performance::r2_nakagawa(m2))
print(performance::r2_nakagawa(m3))

# AIC comparison
cat("\n--- AIC Values ---\n")
cat("Model 0:", AIC(m0), "\n")
cat("Model 1:", AIC(m1), "\n")
cat("Model 2:", AIC(m2), "\n")
cat("Model 3:", AIC(m3), "\n")

################################################################################
# 5. Sensitivity Analyses – Multiple Imputation
################################################################################

# Variables to impute
vars_to_impute <- c("pss_totalday",
                    "pmdd_21_breasttension", "pmdd_22_breast_sensitivity",
                    "pmdd_23_breast_swelling", "pmdd_24_headache",
                    "pmdd_25_joint_pain", "pmdd_26_muscle_pain",
                    "pmdd_27_perceived_weight_gain", "pmdd_28_weight_gain")

# Multiple Imputation using Predictive Mean Matching
imp <- mice(data[vars_to_impute], m = 20, method = "pmm", seed = 123)

# Combine imputed datasets with fixed variables
data_imp_long <- complete(imp, action = "long", include = TRUE)
data_imp_long$Participant <- rep(data$Participant, times = imp$m + 1)
data_imp_long$`Cycle Phase` <- rep(data$`Cycle Phase`, times = imp$m + 1)
data_imp_long$Age <- rep(data$Age, times = imp$m + 1)
data_imp_long$BMI <- rep(data$BMI, times = imp$m + 1)
```

```
data_imp_long$mental_health_diagnosis <- rep(data$mental_health_diagnosis, times =
imp$m + 1)

# Derived variables
data_imp_long <- data_imp_long %>%
  mutate(`Cycle Phase` = tolower(trimws(`Cycle Phase`)),
         phase_bin = ifelse(`Cycle Phase` == "perimenstrual", 1, 0)) %>%
  group_by(Participant, .imp) %>%
  mutate(
    symptom_index = rowMeans(across(starts_with("pmdd_2")), na.rm = TRUE),
    pss_bt = mean(pss_totalday, na.rm = TRUE),
    pss_wi = pss_totalday - pss_bt
  ) %>%
  filter(n() > 1) %>%
  ungroup()

imp_ready <- as.mids(data_imp_long)

# Multilevel models (Rubin's pooling)
fit_m1 <- with(imp_ready, lmer(symptom_index ~ pss_wi + pss_bt + (1 | Participant)))
fit_m2 <- with(imp_ready, lmer(symptom_index ~ pss_wi * phase_bin + pss_bt + (1 |
Participant)))
fit_m3 <- with(imp_ready, lmer(symptom_index ~ pss_wi * phase_bin + pss_bt +
                               Age + BMI + mental_health_diagnosis + (1 |
Participant)))

pool_m1 <- pool(fit_m1)
pool_m2 <- pool(fit_m2)
pool_m3 <- pool(fit_m3)

# Output
summary(pool_m1)
summary(pool_m2)
summary(pool_m3)

# Mean AICs across imputations
get_mean_AIC <- function(fit_object) {
  aic_values <- sapply(fit_object$analyses, AIC)
  mean(aic_values)
}

aic_table <- data.frame(
  Model = c("Model 1 (Stress only)",
            "Model 2 (+ Cycle Phase)",
            "Model 3 (+ Controls)"),
  Mean_AIC = round(c(get_mean_AIC(fit_m1),
                     get_mean_AIC(fit_m2),
                     get_mean_AIC(fit_m3)), 2)
)
print(aic_table)

################################################################################
# 6. Alternative Stress Operationalization – Momentary Stress
################################################################################

# Compute mean momentary stress per day
data$momentary_stress <- rowMeans(data[, c("PSS_1","PSS_2","PSS_3","PSS_4")], na.rm
= TRUE)

# Within- and between-person components
data <- data %>%
```

```
  group_by(Participant) %>%
  mutate(pss_bt_mom = mean(momentary_stress, na.rm = TRUE),
         pss_wi_mom = momentary_stress - pss_bt_mom)

# Models
m1_mom <- lmer(symptom_index ~ pss_wi_mom + pss_bt_mom + (1 | Participant), data =
data)
m2_mom <- lmer(symptom_index ~ pss_wi_mom * phase_bin + pss_bt_mom + (1 |
Participant), data = data)
m3_mom <- lmer(symptom_index ~ pss_wi_mom * phase_bin + pss_bt_mom +
                 Age + BMI + mental_health_diagnosis + (1 | Participant), data =
data)

summary(m1_mom)
summary(m2_mom)
summary(m3_mom)

# AICs
cat("\n--- AIC Values (Momentary Stress) ---\n")
cat("Model 1:", AIC(m1_mom), "\n")
cat("Model 2:", AIC(m2_mom), "\n")
cat("Model 3:", AIC(m3_mom), "\n")
```