2021

Cyclical Change in the Sleep-Emotion Relationship

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CYCLICAL CHANGE IN THE SLEEP-EMOTION RELATIONSHIP

A DISSERTATION SUBMITTED TO

THE FACULTY OF THE COLLEGE OF ARTS AND SCIENCES

IN CANDIDACY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

BY

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BOSTON, MASSACHUSETTS

SEPTEMBER 2021

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ABSTRACT

Research has begun to elucidate psychological processes involved in optimal sleep experience; the current study examines how sleep reciprocally relates to emotional valence and emotional arousal. To understand the nature of sleep-wake emotional cycles, the compatibility of sleep theory and dimensional emotion theory needs to be tested. The current ecological momentary assessment (EMA) study examines patterns that construct (a) emotion characteristics that predict sleep and (b) sleep components that predict emotion characteristics and their fluctuation. Longitudinal multilevel data was collected from 198 adult participants via an online platform. Participants completed a measure of baseline insomnia severity status. For up to 20 mornings and evenings, participants completed self-report measures of sleep (sleep onset latency and sleep quality) and emotion (circumplex arousal and valence). Order effect variability was controlled for through counterbalanced randomization. Data was analyzed idiographically using multilevel lagged regressed change score analysis, portraying discrete relationships between sleep-emotion EMA datapoints as oscillating over time. Iterations of sleep-emotion relationships were tested systematically to compare significant and non-significant predictions and relative impacts. Results indicated that good sleepers integrate their emotional experiences differently from how poor sleepers integrate their emotional experiences. For good sleepers, better sleep quality predicts robust experiences of positive valence the next day. Additionally, good sleepers exhibit circumplex emotional interaction between valence and arousal in the evening to encourage efficient sleep onset. Poor sleepers do not experience either pattern; instead, they experience disjointedness of sleep and emotional integration guided by heightened emotional arousal. A cyclical model of sleep-emotion circumplex integration is proposed and discussed in relation to assessment of insomnia, interventions for insomnia, and future directions for research.

There is a strong line of research demonstrating a relationship between sleep and emotion (Babson and Feldner, 2015). Close relationship between sleep and emotion constructs has been shown to exist among people with both sleep and emotional disorders. Emotional issues are exhibited in sleep based disorders like insomnia disorder (Harvey, 2002; Harvey, 2009; Vanek et al., 2020) and parasomnias (Settineri et al., 2019). Episodic and chronic insomnia symptoms are also found to covary with wakefulness based emotional disorders like anxiety and depression (Harvey et al., 2011; Hellberg et al., 2019; Kloss & Szuba, 2003; Lancee et al., 2017; Mason & Harvey, 2014; Riemann et al., 2019). An empirical mystery remains regarding how core emotional components operate in tandem in a sample of healthy sleepers (Pettersson et al., 2013), and specifically what healthy emotional oscillation looks like. This question of the core components of sleep-emotion integration in subjective experience have not been tested. The current ecological momentary assessment (EMA) study therefore tests predominant circumplex patterns that integrate with sleep onset latency and sleep quality, two subjective bookends that support the integrity of the sleep experience and self-perception.

In a study published by *Psychological Bulletin* in 2013, authors Kuppens, Tuerlinckx, Russell, and Barrett—Russell coined the circumplex emotional framework, comprised of subjective valence and arousal (Russell, 1980; Russell & Barrett, 1999)—discovered that idiographic representation of the emotional circumplex is essential for understanding wakeful well-being. Certainly, a focus on examining emotion in wakefulness is important for psychological science and clinical application; however, the emotion literature and sleep literature are too often mistaken to symbolize orthogonal sides of a coin that is intrinsically reciprocal. To date, it is unknown how idiographic circumplex emotional patterns operate to predict sleep and how sleep patterns operate to predict emotional experience.

Circumplex Emotion Model and Sleep

The current EMA study conceptualizes a circumplex foundational approach to emotion operationalization. To date, there are no published studies informed by integration between the circumplex model and sleep; however, a review of extant evidence suggests that circumplex sleep integration is indeed an important research topic (Baglioni et al., 2010) relevant to psychological experience. A large body of research literature operationalizes emotion as specific terms or labels in surveys; for example, asking participants about their relative levels of sadness, fear, anger, joy, serenity (Smith & Lazarus, 1990; Kalmbach et al., 2014; Wassing et al., 2019). From a conceptual standpoint, one drawback of studying emotion through such labels is that the underlying components or circumplex dimensions of emotion arousal and valence are not assessed. In essence, linguistic labels or top down conceptual markers are studied disproportionately more than studies of bottom up foundational emotional experience. Considered common factors of emotion, the circumplex dimensions in combination is a more parsimonious representation than the myriad of qualitative emotion labels. From a procedural standpoint, recent evidence demonstrates that naming one's emotions often impedes regulation of the emotion, in essence crystallizing the emotional experience and making it more resistant to modification (Nook et al., 2021). To more fully examine the reciprocal interplay with emotion and sleep, research must focus on the foundational wake-sleep-wake flow of experience. No published research to date has examined the circumplex emotion model in the context of sleep.

To address the complexity of these topics on how emotion patterns relate to sleep over time, the Introduction will focus on two main ways that sleep-emotion integration occurs in subjective experience, then describe how they relate to each other. Initially, basic representation of sleep-emotion integration is broadly described. Next, relationships are described between

sleep and emotional valence and then between sleep and emotional arousal. These two relationships are delineated, in separate sections, for the purpose of eliciting in the reader's imagination of the rudimentary components of emotion. With these rudimentary axes of the emotional circumplex in mind, arousal and valence interplay is described in relation to sleep. The small body of extant literature exploring sleep-emotion integration is then critiqued. To account for limitations of the extant literature, a combination of novel hypotheses is proposed, which are designed to test for the presence of a perceived sleep-emotion cycle.

Sleep-Emotion Integration

Given extant evidence supporting the presence of dimensional models of emotion within normative and psychopathological phenomena (Alfano et al., 2014; Argyriou & Lee, 2020; Pettersson et al., 2013; Posner et al., 2005; Scott et al., 2020), the current EMA study assesses how two key sleep variables—sleep onset latency and sleep quality—relate to two clearly identified emotion dimension variables—valence and arousal—across pre-sleep and post-sleep interval cycles. The dimensional circumplex model (Russell, 1980) purports that emotional phenomena can be represented as the combination of these two dimensions. Arousal refers to the felt activation, the degree to which one is activated versus deactivated, within an emotional representation. Valence refers to the hedonic tone, the degree to which one feels pleasure versus displeasure, within an emotional representation. The plotting of arousal and valence in combination organizes emotional states at a specific time point along two axes (Russell, 1980; Russell & Barrett, 1999). In research on sleep and emotional well-being, the pre-sleep and post-sleep periods are two timepoints that can offer clues about how sleep and emotional subjective experiences inform each other (Antunes-Alves & De Koninch, 2012; Nixon et al., 2017). It is anticipated that arousal might be more related to sleep onset latency and valence more related to

appraisal of sleep as good or bad in quality (Fairholme & Manber, 2015); however, these links have yet to be studied in tandem.

Knowledge about important sleep based intervals lends coherency to theory and application informing knowledge of wakeful representation of well-being (Hu, Wang, Sun, Arteta-Garcia, & Purol, 2018). Two important subjective sleep variables are of interest. Sleep onset latency and sleep quality are considered reliable and important indicators of sleep health and more generally, of overall health as an ordinary health variable for living well (Blake et al., 2018; Buysse et al., 1989; Gruber et al., 2015). Sleep onset latency is defined as the time taken to fall asleep after someone begins attempting to fall asleep. Sleep quality is defined as how refreshed someone feels upon wakening. While sleep quality is better accounted for by self-report measures than by objective measures (Goelema et al., 2019), it has been found to mediate the effect of objective sleep on enduring emotional states (Bei et al., 2015; Bei et al., 2017) and it predicts next-day positive emotion (de Wild-Hartmann et al., 2013). When compared to sleep duration, sleep quality better represents the psychology of sleep experience (Bathgate et al., 2016; Tavernier and Willoughby, 2014) as it reflects the post-sleep appraisal of how refreshed an individual feels upon waking. Sleep quality also relates more closely to emotional valence than sleep duration does (Shen et al., 2018). Within the context of insomnia, subjective sleep quality is particularly related to quality of life (Harvey et al., 2008). Empirically, combined study of sleep onset latency and sleep quality can provide foundational information about daily pre-sleep and post-sleep demarcation of sleep-wake-sleep intervals, related to emotional oscillation.

Emotional valence and sleep. A benefit of the circumplex framework is that its corresponding measurement allows depiction of shifting across a positive-to-negative valence spectrum, elucidating emotional fluctuation patterns that vary based on subjectively experienced

hedonic tone (Bouwmans et al., 2017; Shen et al., 2018; Kalmbach et al., 2014). A limitation of the literature is that positive and negative valence have often been modeled orthogonally along separate axes, rather than along one continuum of positive-to-negative valence that informs subjective emotional quality (Nezlek & Kuppens, 2008), distinct from an activation continuum (Madrid & Patterson, 2014; Russell, 1980). Evidence supports a link between valence and sleep quality, specifically, in which sleep seems to be a strong predictor of wakeful emotional valence (Feige et al., 2019; Vandekerckhove et al., 2012). Relating to wakeful wellness, a ratio of higher positive emotion to lower negative emotion is seen to characterize wakeful emotional well-being (Kahn et al., 2013; Vulpe & Dafinoiu, 2011). Better sleep quality has been found to have a buffering effect on emotional well-being by encouraging greater positive emotion and less negative emotion (Wichers et al., 2007). In comparison to sleep quality, the relationship between valence and sleep onset latency has been underexplored. Continuity and discontinuity in emotional valence may impact sleep onset latency and/or may be impacted by sleep onset latency.

Emotional arousal and sleep. Emotional arousal is a functionally distinct construct that is central to an emotional experience and requires effective regulation to achieve well-being. Consider one's level of subjective emotional arousal that exists at the beginning of the day following a night of sleep, compared to the level of subjective emotional arousal at end of the day preceding a night of sleep. One's ability to fall asleep efficiently (Wuyts et al., 2012) and feel activated and alert in the post-sleep morning period (Fisk et al., 2018) indicates adaptively timed regulation of emotional arousal. Heightened arousal in the pre-sleep period impedes sleep onset and sleep quality (Shoji et al., 2014; Tavernier et al., 2016; Tousignant et al., 2019), suggesting that pre-sleep emotional experience and next-morning emotional experience may be

related. Although the importance of the de-arousal process was articulated three decades ago (Sewitch, 1987) and is known to impact the pre-sleep period (Feige et al., 2019; Krone et al., 2017; Sunnhed & Jansson-Frojmark, 2015), no published research has yet examined both de-arousal process and the valence regulation process embedded across a 24-hour context. To understand how the circumplex framework operates in the context of a reciprocal sleep-wake-sleep framework, arousal and valence need to be studied in tandem.

Expanding on the Extant Literature

To date, just three studies have used EMA measurement to assess daily sleep and emotional constructs (Bouwmans et al., 2017; de Wild-Hartmann et al., 2013; Talbot et al., 2012). The value of EMA studies is instrumental for elucidating knowledge of how emotional constituents change over nights and days, and these three studies offer important information about the topic. Talbot and colleagues (2012) examined relationships between sleep duration and negative mood assessed as six broad scales: tension-anxiety, depression-dejection, anger-hostility, fatigue, confusion, and vigor. In this representation, the vigor subscale was the only one that assessed positive valence. Patterns of emotional valence in a sample of people with no psychiatric history were compared to a sample of people with insomnia disorder. Negative valence was associated with worse sleep whereas there were no group differences in positive valence (Talbot et al., 2012). The lack of group differences for positive affect may have resulted because sleep duration was examined, not sleep quality. The validity of findings by Talbot and colleagues (2012) needs to be further clarified, in part because negative valence and positive valence were disproportionately represented in the study design. Another limitation that needs to be corrected was that the use of MANOVA to analyze EMA data condenses numbers thereby impeded the ability to detect granularity of effect from day-to-day.

Clarifying knowledge about relationships between sleep and post-sleep and pre-sleep wakeful intervals, de Wild-Hartmann and colleagues (2013) found close association between sleep and emotion using an EMA procedure. A strength of their study (de Wild-Hartmann et al., 2013) is its naturalistic design and repeated measures data collection that allowed representation of post-sleep and pre-sleep emotion within the sleep-wake-sleep cycle. Average sleep quality and positive emotion were strongly associated ($p < .001$). While sleep quality had inverse association with post-sleep negative emotion, pre-sleep negative emotion was not found to impact sleep experience. This finding informed the current EMA study's second hypothesis as replication that sleep quality would predict next-day emotional experience.

One limitation of their study (de Wild-Hartmann et al., 2013) was that results were derived from data reflecting a participant's average emotional experience. The use of average scores within a regression model, to analyze EMA data, also condenses numbers too much to represent natural fluctuation of day-to-day experience. Another limitation of the study was that emotion was operationalized without evidence-informed theoretical underpinning, in comparison to the circumplex model that holds evidence-informed theoretical underpinning (Russell, 1980). To operationalize emotion, de Wild-Hartmann and colleagues (2013) offered participants ten adjectives for rating their mood. Positive emotion words included *cheerful, content, energetic,* and *enthusiastic,* and negative emotion words included *insecure, lonely, anxious, low, guilty,* and *suspicious*. Emotional constructs like *content* and *enthusiastic*, though qualitatively distinct in their arousal component, were not differentiated. Additionally, averages of the four positive emotion words and the six negative emotion words were used in analyses relating emotion to sleep. Averages of these specific words do not portray the full scope of emotional experience. Moreover, core emotional constructs like anger and disgust were not represented, which limits

the generalizability of the study findings. The circumplex emotional model is empirically superior because it allows for any emotion to be reflected based on valence by arousal ratings.

Using ambulatory assessment study design with repeated assessments, Bouwmans and colleagues (2017) first elucidated the presence of temporal causality between sleep and emotion. Good sleep was found to predict next-day increased positive emotion and decreased negative emotion whereas pre-sleep emotion did not predict subsequent sleep (Bouwmans et al., 2017). Unfortunately, in this study the specificity of information gleaned was limited by collapsing emotion ratings into an average score, representing a period from 10:00 AM to 10:00 PM of wakefulness, for analysis. The use of averages is discouraged because they do not capture non-linear variability (Barry, 2017) characterizing psychological experience. In understanding the sleep-wake cycle, the timing of emotional experience in relation to sleep is of paramount importance to understanding the manner in which psychological dynamics change over time. Another limitation of the study by Bouwmans and colleagues (2017) that needs to be addressed is that the small sample size (*n* = 29) narrows the portion of the population to which results can be generalized. With repeated measures data for each participant, a small sample size does not preclude meaningful results (Cicchetti, 2001); however, the use of averages with a small sample size yields crude results.

To account for this limitation, the current EMA study uses a larger sample size of individuals with varying levels of insomnia in the general population. According to the *DSM*-5 (2013), population-based estimates find that about 33% of adults in the general population report insomnia symptoms, 10-15% of adult experience daytime impairments related to insomnia symptoms, and 6-10% of adults meet criteria for moderate to severe insomnia disorder. Disruptions to sleep are categorized as insomnia symptoms. By definition of its first criteria,

insomnia disorder evolves when the individual has a predominant issue with sleep quality and/or sleep quantity, often characterized by difficulty initiating sleep (*DSM*-5, 2013). Along a continuum or gradient of insomnia severity, the current research seeks to elucidate gradual changes in emotional oscillation patterns that may signal the emergence of insomnia patterns.

Proposed Sleep-Emotion Cycle Contextualized within Time and Insomnia

A multitude of results from experimental and correlational studies have confirmed the presence of a close relationship between sleep and emotion (Babson and Feldner, 2015; Baglioni et al., 2010). Central to current empirical knowledge are the findings that pre-sleep arousal is associated with poor sleep, and that poor sleep is related to greater negative emotion (Ong et al., 2011) and less positive emotion (de Wild-Hartmann et al., 2013) during the day. Pre-sleep and post-sleep intervals of subjective experience inform good sleep and are proverbial bookends to appraising wakeful emotional well-being (Hu et al., 2018). One's constructed emotional experience at these critical intervals can influence perception of one's ability to fall sleep and benefit from sleep. In relation to symptoms of insomnia such as rumination and worry, pre-sleep arousal is a variable that prolongs SOL (Tousignant et al., 2019), and SOL inversely covaries with sleep quality (Goelema et al., 2019). Sleep quality has been found to predict next-day wakeful emotional well-being (Bouwmans et al., 2017; Nota & Coles, 2018). Greater positive emotion and less negative emotion signifies emotional well-being, a leading indicator of psychological health. However, comparative impacts of sleep quality on next-day arousal and valence have not been explored. Patterns by which circumplex emotional interplay, between arousal and valence dimensions, impact SOL also have not been studied.

Modeling a cycle is made possible by the combination of EMA data collection aggregated and analyzed through level-1 and multilevel lagged regressed change analysis. To represent the sleep-wake-sleep cycle over time, the following hypotheses are examined:

Hypothesis 1 testing emotion-sleep directionality: Positive emotional valence and low pre-sleep emotional arousal will predict shorter SOL and better sleep quality. Post-sleep to pre-sleep arousal reduction will be inversely related to SOL such that participants reporting post-sleep to pre-sleep arousal reduction will report shorter SOL compared to people reporting post-sleep to pre-sleep arousal plateau (i.e., no change) or increase.

Hypothesis 2 testing sleep-emotion directionality: Sleep quality will be positively associated with evening-to-morning change in valence and evening-to-morning change in emotional arousal. Participants reporting better sleep quality will report a pre-sleep to post-sleep shift toward positive emotion, as well as increased emotional arousal overnight.

Hypothesis 3 testing emotional interplay with insomnia: Insomnia severity will be (a) positively associated with post-sleep to pre-sleep arousal reduction impacting SOL, (b) inversely associated with positive valence in the morning and evening, and (c) associated with different valence and arousal interplay patterns compared to when insomnia is not included in the model.

Method

Participants

For the current EMA study, 198 participants were recruited through MTurk, an international online task-sourcing website. An *a priori* power analysis was conducted using *G*Power 3* software to determine the minimum sample size necessary for the current study (Faul

et al., 2007; Faul et al., 2009). The power analysis was based on an alpha probability level of 0.05, a statistical power level of 0.95, and an anticipated effect size of 0.80. The analysis indicated that a baseline sample size of 168 participants would be necessary. To preemptively account for attrition, the study therefore over-enrolled to 198 participants, to increase the odds of obtaining the necessary amount of data points for multilevel lagged regressed change analyses. The quality of data from online longitudinal studies is comparable to that of traditional longitudinal methods (Schleider & Weisz, 2015). Several data quality checks were conducted to detect and clean the data.

Eligibility criteria required that participants were at least 18 years of age, fluent in English (minimum high school degree), and that they had regular access to the internet. Exclusion criteria also required that participants were not taking sleep medications or medications that depress or activate the central nervous system, were not addicted to alcohol or drugs, and did not work overnight shifts. For quality data control, only participants with a history of satisfactory approval ratings and feedback on previous tasks (95% approval rating for previous Mechanical Turk tasks completed) were allowed to access the study.

The sample exhibited moderate demographic heterogeneity in representing a range of years across adulthood. Participants' ages ranged from 20-72 (M_{age} = 42.37 years, SD_{age} = 12.31). Approximately 46.3% of the sample (n = 88) identified as male, 52.6% of the sample (n = 100) identified as female, 0.5% of the sample (n = 1) identified as non-binary, and 0.5% of the sample (n = 1) identified as transgender male. Regarding racial demographics, 18.9% of the sample (n = 34) identified as an individual of color and 81.1% of the sample (n = 146) identified as a white individual. Regarding identities as racial and ethnic minorities, 6.7% of the sample (n = 12) identified as Hispanic or Latinx, 5.6% of the sample (n = 10) identified as Black or African

American, 5.6% of the sample (*n* = 10) identified as Asian, and 1.1% of the sample (*n* = 2) identified as Native American. No participants selected more than one racial identity. Each individual in the sample (*n = 190;* 100.0%) indicated having at least one ethnic identity. The majority of the sample (*n* = 147; 77.4%) reported having a Caucasian identity (e.g., *American, Euro-American)* and about a quarter of the sample (*n* = 43, 22.6%) reported having a more diverse ethnic identity (e.g., *Puerto Rican, Chinese, Dominican, Korean, Greek, Indian, Italian, Japanese, Middle Eastern, Spanish, Thai*). Approximately 73.2% of the sample (*n* = 139) reported having a religious identity, with heterogeneity among participants' religious orientations.

Measures

Baseline self-report measure. *The Insomnia Severity Index* (ISI; Appendix A3; Bastien et al., 2001) assesses subjective perception of recent episodic insomnia experiences. Items use a seven-point Likert scale and reported based on the past two weeks. Some examples of items include: *Rate your current (i.e., last two weeks) symptom severity for having difficulty falling asleep* (none, mild, moderate, severe, very severe, 1-5 Likert scale); *How satisfied/dissatisfied are you with your current sleep pattern?* (satisfaction rating, 1-5 Likert scale); and *To what extent do you consider your sleep problem to interfere with your daily functioning (e.g., daytime fatigue, mood, ability to function at work/daily chores, concentration, memory) currently*? (interference rating, 1-5 Likert scale).

Scores on the ISI range from zero to 28 with higher scores signifying worse insomnia severity (Morin et al., 2011). This measure distinguishes people with insomnia from people without insomnia (Wong et al., 2017). Its scoring system allows four-level differentiation (non-clinically significant, subthreshold, moderate, or severe insomnia) and representation as a scale

variable. The dichotomization approach to insomnia classification is overutilized in research, and insomnia severity may be better represented with greater nuance (Akram, 2020; Sarsour et al., 2010) as a continuous variable. The ISI has good convergence with measures of subjective and objective sleep as well as with daytime dysfunction (Wong et al., 2017). The ISI also has good internal consistency (α = .75; Gerber et al., 2016) and criterion validity with other sleep measures like the Pittsburgh Sleep Quality Index (r = .69, p < .001; Lin et al., 2018). The current study seems to be the first to use the ISI in conjunction with circumplex emotional measurement (Bradley & Lang, 1994; Lang, 1980). Within the current sample, there was strong internal consistency of the ISI (α = .92).

Daily self-report measures. *The Consensus Sleep Diary* (Appendix A4; Carney et al., 2012) is a standardized prospective self-report measure used to assess SOL and sleep quality (Maich et al., 2018). In research and clinical contexts, sleep diaries are considered a gold standard for tracking sleep patterns across time (Buysse et al., 2006). SOL is operationalized as a number of minutes and is calculated using the items, "*What time did you get into bed? Write the time you got into bed, this may not be the time that you began trying to fall asleep;* and *What time did you try to go to sleep?*; and *How long did it take you to fall asleep?* Sleep quality is assessed with the item, "*How would you rate the quality of your sleep? 'Sleep quality' is your sense of whether your sleep was good or poor"* using a five-point Likert scale (1 = *very poor* to 5 = *very good*). Research has found that insomnia is more related to the ability to fall asleep efficiently than it is to the number of minutes or time spent in bed (Vincenzo et al., 2015). This is the distinction of sleep onset latency (SOL) as opposed to shuteye latency as time spent doing activities in bed before sleeping (Exelmans et al., 2018). For perception of sleep, the

straightforwardness of the SOL item complements that of the sleep quality item, together symbolizing an overnight sleep phase.

The items assessing SOL and sleep quality have been used as daily measurements in prior studies and has demonstrated good internal consistency (α = 0.89; Knufinke et al., 2018; Fung et al., 2014; Tousignant et al., 2018; Winzeler et al., 2014). The literature demonstrates their independent relationship with emotional experience as well as their unique addition of variance to the sleep experience (Hermans et al., 2021; Hermans et al., 2020). The time it takes to fall asleep at night (SOL) is considered independent of the degree to which someone feels refreshed upon awakening the next morning (sleep quality), yet healthy sleep is reflected by both sleep parameters (Ohayon et al., 2017). Imagining the sleep phase as a continuum over the night, SOL and sleep quality represent bookends for the sleep consciousness transitions in the evening and in the morning, respectively. The sleep onset time of immersing into sleep occurs immediately prior to sleep (pre-sleep bookend) whereas subjective sleep quality awareness occurs immediately after sleep upon awakening (post-sleep bookend).

Sleep onset latency and sleep quality are two critical sleep parameters that are reliable and valid in identifying subjective sleep experience. Each independently relating to measures of well-being, SOL and sleep quality are two variables often studied in tandem (Lemola et al., 2013; Vleeshouwers et al., 2016). For approximating these sleep parameters, the Consensus Sleep Diary (CSD) has been found to be used to study SOL and sleep quality and to distinguish between poor sleepers and good sleepers (Carney et al., 2012; Maich et al., 2018). To our knowledge, the current EMA study is the first research to compare operation of SOL and sleep quality within the context of an insomnia gradient. Additionally, the CSD recently has been used in conjunction with emotion label variables (Bouwmans et al., 2017; Leger et al., 2019) but not

yet with the Self-Assessment Manikin symbolizing the circumplex framework.

The Self-Assessment Manikin (SAM; Bradley & Lang, 1994; Lang, 1980) is a two-item 9-point Likert scale for assessing arousal and valence emotion dimensions. The points on the scale are denoted by a character graphic, contributing to its cross-cultural utility as a nonverbal instrument. Additionally, it is sensitive to detecting change in arousal and valence between time points (Buysse et al., 2007). The arousal characters range from a face with eyes closed looking calm to a face with eyes open looking alert. The valence characters range from a face with a frown to a face with a smile. The SAM demonstrates strong internal consistency reliability in adult populations (Backs et al.,, 2005). In a study assessing responsiveness to stimuli from the International Affective Picture Scale (Alfano et al., 2014; Backs et al., 2005; Lang et al., 2005), Chronbach's alpha levels ranged from 0.63 – 0.82 for valence and congregated around 0.98 for arousal. Additionally, SAM criterion validity is strong regarding its ability to predict norms for arousal (R^2 = 0.74, F(1, 178) = 507.87, p < .001) and valence (R^2 = 0.93, F(1, 178) = 2260.31, p < .001; Backs et al., 2005).

The SAM has strong convergent validity with psychophysiological measures (Bradley et al., 1992) and it has been suggested to have good discriminant validity for detecting differences in poor sleepers and good sleepers (Ong et al., 2011). Its valence scale has been used in demonstrating that poor sleep quality predicts reduced emotional empathy in response to negative images (Guadagni et al., 2018). Findings from a study led by the creator of the SAM also suggest strong convergent validity of SAM valence and arousal emotion ratings with objective measures of affect (Lang et al., 1993). Self-reported emotional valence significantly covaried with an objective affective assessment (i.e., facial electromyographic). Self-reported emotional arousal significantly covaried with another objective affective assessment (i.e., skin

conductance response). Healthy people may not represent arousal and valence as comprising an emotional experience (Barrett et al., 2001; Suvak et al., 2011), so this measure's queries about feelings, rather than emotion, appropriately assesses activation level and pleasantness of internal experience. These aforementioned measures connect to our primary research questions.

Procedure

The study consisted of baseline measurements (demographics, ISI, and those included in Measures document) and then up to 20 days of prospective measurements that took approximately 1-2 minutes (Buysse et al., 1989). After reviewing inclusionary criteria and the informed consent document (Appendix A1), participants completed a series of self-report measures on their electronic device of choice. Baseline assessments and repeated measures data were collected to calculate idiographic statistics and models, informed here by insomnia nomothetic principles as recommended (Wright & Zimmermann, 2019). For up to 20 days, participants either completed measures of emotion (valence and arousal) first and then measures of sleep, or they completed measures of sleep first and then measures of emotion. Survey order assignments were counterbalanced across participants based on randomization. Each morning at 6:00 AM EST and each evening at 4:00 PM EST, participants were emailed a link via Qualtrics for that specific timepoint. Similar timepoints have been used in psychological and sleep studies modeling repeated measures (Bouwmans et al., 2017; Minkel et al., 2011; Wolkow et al., 2015).

Analytic Approach

The current EMA study's analytic approach reflects applied longitudinal data analysis from a multilevel regression framework (Hayes, 2018; Singer & Willett, 2003) that depicts change over time calculated using repeated assessments of sleep parameters and emotional dimensions, across post-sleep to pre-sleep to post-sleep periods. Multilevel analysis was

conducted for several reasons. The first reason was because the analysis readily manages time intervals between assessments. Morning and evening repeated timepoints yield the model's detection of a cadence (Singer & Willett, 2003) along the wake-sleep-wake continuum in subjective awareness. Lagged change scores were calculated and modeled because change over time is intrinsic to understanding how sleep and emotion variables oscillate in subjective awareness and within the context of one's self-appraisal of insomnia severity.

Time is a fundamental predictor in the current study. The second reason for conducting multilevel analysis was to model within-person data nested within between-person data. The nested data structure was classified as individuals nested in time within a 24-hour cycle, which was nested in two intervals of morning evening wake-sleep transition (Hypothesis One) and sleep-wake transition (Hypothesis Two), which was further nested in episodic insomnia experience from the past two weeks (Hypothesis Three) as recent insomnia experience. The third reason multilevel analysis was selected is because the algorithmic structure makes it robust to missing data (Hayes, 2018), including all within-participant assessments in the estimation of the final model. To be included in the analyses for study, participants needed to have at least two consecutive ratings that allowed a change score predictor to be calculated. Finally, the fourth reason that multilevel analysis was conducted was due to its flexibility for modeling multiple outcomes and predictors as systematic iterative data (Singer and Willett, 2003; Snijders and Bosker, 2012; https://stats.idre.ucla.edu/spss/seminars/spss-mixed-command/).

Results

All analyses were conducted using SPSS and Microsoft Excel. The dataset included 809 paired morning and evening emotion scores and was comprised of 114 participants with repeated measures data. Within this sample, 110 participants had at least two consecutive timepoints to be

included in change-score hypothesis testing. Paired timepoints ranged from 1-20, as wave 1 data collection included up to 20 daily timepoints whereas wave 2 and wave 3 data collection included up to 10 daily timepoints. Among 809 total consecutive daily timepoints, on average participants had 5.81 timepoints (*SD* = 4.16). Analyzing retention and data collection, 190 participants of the original 198 participants (95.9%) completed daily data. As such, 110 participants of those 190 participants (57.9%) had at least two consecutive timepoints and thus were included in multilevel lagged regressed change score analyses.

Multilevel lagged regressed change analyses were chosen for several reasons to represent this clustered longitudinal EMA data. Multilevel modeling is a cutting edge statistical area that is continually updating (Gordon, 2019), is known to account for nested data, and allows for probing of within-level interactions. Within the current study, sleep-emotion assessments were nested within individuals (level 1) and individuals were nested within insomnia scores (level 2). Idiographic sleep-emotion interactions were tested, and idiographic insomnia moderated interactions were further tested. Additionally layered, this data was then nested within time-of-day intervals. Another asset to the current analysis, lagged-day and lagged-night scores were modeled to address change over time. Lagged effect estimates change depending on the time that elapses between measurement waves (Kuiper et al., 2019). Currently, there is no best practice established for how to handle the time interval in lagged regressed change models (Kuiper et al., 2019), but commonly accepted practice is to treat the time intervals as linear predictors (Card, 2019). Emotional patterns across linear wake-sleep-wake intervals may shift in cyclical manner.

Power analyses were conducted in accordance with steps recommended by statistical experts in the field (e.g., Cohen, 2013; Lorah, 2018; Pituch & Stevens, 2016). Power of a statistical test is defined as the probability of rejecting the null hypothesis when it is false. Put

another way, power is the probability of making a correct decision or saying the model predicts meaningful patterns detectable above and beyond the effects of chance alone (Pituch & Stevens, 2016). Power is dependent on sample size. At group sizes greater than 200 participants, most effects will be declared statistically significant at the $p < .05$ level. If statistical significance is revealed, Pituch and Stevens (2016) recommend looking at confidence intervals, effect size measures, and/or measures of association as variance accounted for; impacts of collective subjective weights. Quoting *By Design* (1990) by Light and colleagues, Pituch and Stevens (2016) remind us, "because practical significance depends upon the research context, *only you* can judge if an effect is large enough to be important" (p. 195); in essence, subjective experience is paramount. Most behaviors have multiple causes or emotional precursors and outcomes; in research it is difficult to account for a large amount of variance with just single causes (Pituch & Stevens, 2016). Notably, the situation is different if longitudinal ecologically valid repeated measures are assessed at equidistant intervals over time, as exists in the current EMA study.

In this scenario, we as authors believe it is statistically acceptable to assume equivalent impact of random effects between variables impacting sleep scores and emotion scores. In the current EMA study, comparisons between our population's self-reported sleep and emotion patterns are compared to the hypothetical general population of individuals who hypothetically do not have meaningful associations between their sleep and emotion scores. Given the nascent psychological literature linking dimensional emotion and wake-sleep-wake transition, the current study's findings are an exemplar starting point about how subjective experience of sleep and subjective awareness of emotion operate in conjunction to impact each other. Over time, the toggling back and forth between diurnal perceptions is seen as important for understanding sleep related oscillation and potential intervention points to address episodic insomnia and circumvent

the transition to more frequent episodes of insomnia (Baglioni et al., 2010; Carciofo, 2020; Carciofo et al., 2021; Ellis et al., 2021; Wassing et al., 2019).

Sleep Variables

The distribution of study variables was examined prior to conducting analyses. As expected, the insomnia severity variable was skewed right such that that majority of participants had insomnia severity scores of zero. There was linearity in the output graph comparing expected normal to observed value data. The daily SOL variable was skewed right with a modal rating of perceived zero minutes taken to fall asleep. The daily sleep quality variable was skewed left with a modal rating of 4/5. Participants' average level of daily sleep quality was 3.60 (*SD* = 1.01, range = 1-5) and their average minutes to daily sleep onset latency was 18.39 (*SD* = 28.21, range = 0-300). These parameters are consistent with other sleep studies on healthy adult populations (Landry et al., 2015; Lemola et al., 2013).

Regarding insomnia severity among 110 total participants with at least two consecutive daily timepoints, average scores were 7.27 (SD = 6.71, range = 0-24). The Insomnia Severity Index scoring system specifies calculations of quartiles wherein each indicates a gradient of insomnia severity (Morin et al., 2011). Within the sample, 68 participants (61.8% of the sample) exhibited non-clinically significant insomnia scores (range 0-7). With slightly higher insomnia scores, 21 participants (19.1% of the sample) exhibited subthreshold insomnia, 17 participants (15.5% of the sample) exhibited clinical insomnia of moderate severity, and 4 participants (3.6% of the sample) exhibited severe clinical insomnia. This distribution reflects heterogeneity within the sample consistent with expectations from population samples (Ohayon & Sagales, 2010).

Emotion Variables

Morning valence and evening valence were slightly left skewed each with a modal rating

of 5/9 (*1 = negative valence, 5 = neutral valence, 9 = positive valence*; Appendix A5). Morning arousal and evening arousal were slightly right skewed each with a modal rating of 3/9 (*1 = not at all activated, 5 = moderately activated, 9 = extremely activated*; Appendix A5). As such, these emotion combinations within a circumplex framework are considered to reflect daily pillars of emotional equilibrium within a healthy adult population. At pre-sleep and post-sleep intervals, healthy individuals report moderately low levels of arousal and a so-called neutral valence. The current EMA study thus considers the modal illustration by the self-assessment manikin to symbolize waxes and waves along experienced emotional equilibrium. There was a mode of 5/9 for valence and 3/9 for arousal in the morning and in the evening. This demonstrates stability of circumplex emotional experience in the pre-sleep period as in the post-sleep period.

Participants' average morning valence score was 5.91 (*SD* = 1.76, range = 1-9) and evening valence was 6.03 (*SD* = 1.85, range = 1-9). Participants' average morning arousal score was 3.53 (*SD* = 1.76, range = 1-9) and evening arousal was 3.59 (*SD* = 1.89, range = 1-9). Valence and arousal scores were comparable to those in a cross-sectional study of healthy controls such that valence scores were slightly higher than arousal scores (Hüfner et al., 2020). Regarding daily emotion change scores, participants' average morning-to-evening valence score was .15 (SD = 1.71, range = -6-8) and average evening-to-morning valence score was -.15 (SD = 1.78, range = -7-8). Participants' average morning-to-evening arousal score was .04 (SD = 1.82, range = -6-8) and average evening-to-morning arousal score was -.04 (SD = 1.88, range = -8-8).

Preliminary Analyses

Prior to conducting regression and multilevel lagged regressed change analysis, preliminary analyses (below) indicated descriptive data including means, standard deviations, and ranges for all variables. Additionally, key correlations were calculated—with Bonferroni

correction—to glean knowledge of general relationships involved in self-reported integration (i.e., interconnected operation) of sleep experiences and emotional states (Table 1). Table One demonstrates the relative strengths and directions of associations between singular emotion variables and sleep variables. Emotional arousal and valence seem to be distinct yet related constructs that can be modeled in relation to sleep in disparate ways within the EMA stacked dataset using multivariate multilevel lagged analysis (Baldwin et al., 2014; Hayes, 2006; Suvak et al., 2009).

As expected, greater insomnia severity predicted longer SOL whereas lower insomnia severity predicted shorter SOL (*Estimate* = 1.15, *SE* = .24, *df* = 110.56, *t* = 4.77, $p < .001$, *CI* = .67 to 1.63). Given that the stacked dataset allocated an idiographic episodic insomnia score per each EMA emotion assessment, insomnia severity score can be considered more of an idiographic state-based moderator than a nomothetic trait-based moderator. There was a small yet statistically significant association between SOL and insomnia severity ($r = .23$, $p < .001$) and between sleep quality and insomnia ($r = -.394$, $p < .001$). Given the misalignment as level-1 static daily sleep scores versus level-2 more stable or baseline insomnia severity scores within the nested data structure, reciprocal prediction was not tested.

Rationale for Conducting Multilevel Lagged Regressed Change Analysis

The validity of our core results is enhanced by idiographic modeling of EMA data via multilevel lagged regressed change analysis, a novel endeavor. To communicate the dynamics to the reader, parentheses below include confidence intervals as well as the numeric difference or subtraction score of the interval window's width. A window is calculated as the absolute value of the 95% confidence interval difference between the lower bound and upper bound. Confidence interval windows that do not contain zero are considered to be meaningful or significant. More

narrow windows indicate more powerful effects that are less likely to be due to chance or noise.

Beyond comparing the power of main effects through idiographic lagged change score linear regression, the current EMA study further compares interaction effects through idiographic multilevel lagged regressed change score regression. Interaction effects are synonymous with moderation such that the effect or impact of one predictor on the outcome varies across levels of another predictor. To test continuous interactions, all continuous string variables per person were idiographically mean-centered to create interaction terms. Mean centering shifts to a common metric for comparison, demarcated by units of standard deviation. All iterations of emotion change score variables were computed into new variables and systematically examined. Data recoding was conducted prior to analyses testing interaction effects in Hypothesis 3. Amid a range of different opinions about the importance of mean-centering, the recommended approach changes depending on the question of interest (Hayes, 2018).

Given our current approach, based on Kuppens and colleagues' recommendation (2013), each datapoint was mean centered based on the nomothetic group sample. Mean-centering based on the nomothetic sample means that the individual datapoint will likely be further away, and explain more variance from, that sample's mean level or random effects bias. In the current study we wanted to increase the chance of detecting meaningful variability, given that the study is studying granular components of subjective experience. In contrast, hypothetically if the datapoints were mean-centered with each respective individual's mean score, it would essentially be watering down the results. With repeated measures aggregation, nomothetic mean centering of 809 datapoints for comparison adds robustness to the constructs of interest.

Primary Analyses

The below findings reflect more than 809 rows of daily timepoint pairings within the dataset, nested within 110 individuals. Statistical legitimacy is supported by the multitude of input-output iterations of the subjective experience that are recognized through multilevel lagged regressed change score analysis using up to 20 consecutive days of EMA data at pre-sleep and post-sleep intervals. Participants with at least two days of consecutive emotional assessments were included in the lagged regressed change analysis, allowing inference of within-participant patterns to emerge. Investigations of idiographic patterns in sleep-emotion integration were prioritized, given recent seminal research demonstrating that emotional process is better understood idiographically than nomothetically (Kuppens et al., 2013). Lagged regressed change analysis in SPSS was conducted, first as sleep-emotion links nested within individuals (H1 and H2; Table 2) and then as sleep-emotion links nested within individuals nested within insomnia scores (H3; Table 3).

Hypothesis One: Emotion Predicting Sleep

The emotion-sleep impacts that emerged were primarily predictive of SOL, whereas no emotion variables were predictive of sleep quality (Table 4). Six out of twelve (6/12; 50.0%) possible impacts of emotion dimensions on SOL were statistically significant (Table 4). Supporting Hypothesis One, emotional arousal was found to predict SOL. Change from lesser-to-greater emotional arousal overnight predicted shorter time to fall asleep in the interim night (*Estimate* = -1.90, *SE* = .53, *df* = 665.626, *t* = -3.60, *p* < .001, *CI* = -2.93 to -.86; 2.07). The time-dependent manner was different than specified in Hypotheses One. Evening-to-morning trajectory of emotional arousal predicted SOL, whereas morning-to-evening trajectory of emotional arousal did not predict SOL. This suggests that SOL time reported is particularly impacted by one's morning perception of overnight change trajectory of emotional arousal.

Evening arousal was also a singular emotion predictor of the same night's SOL (*Estimate* = 1.90, SE = .59, *df* = 749.59, *t* = 3.21, *p* = .001, *CI* = .74 to 3.06; 2.32) as well as the following night's SOL (*Estimate* = 1.43, *SE* = .58, *df* = 666.52, *t* = 2.48, *p* = .013, *CI* = .30 to 2.56; 2.26). The other circumplex dimension—emotional valence—was also examined as impacting SOL (Table 2). Evening valence exhibited inverse predictive impact on SOL (*Estimate* = -1.79, *SE* = .58, *df* = 750.12, *t* = -3.06, *p* = .002, *CI* = -2.94 to -.64; 2.30). Consistent with expectations, more positive valence in the evening predicted shorter time to fall asleep, whereas more negative valence in the evening predicted longer time to fall asleep. Evening circumplex emotional interplay—defined as an evening interaction effect between valence and arousal—predicted SOL. During the pre-sleep period, valence and arousal exhibited statistically significant interplay to predict the same night's SOL (*Estimate* = -.73, *SE* = .24, *df* = 764.74, *t* = -3.49, *p* = .001, *CI* = -1.32 to -.37; 0.95; Table 5). When evening valence was negative, the positive association between evening arousal and SOL strengthened. When evening valence was positive, the association between evening arousal and SOL did not change. Statistically significant evening interplay operated independent to the main effects of evening valence and evening arousal (Table 5). As seen by comparison of confidence interval window widths, evening emotional circumplex interplay is a particularly strong predictor of SOL.

Neither emotional valence change score predicted SOL. Morning positive morning valence also predicted subsequent SOL (*Estimate* = -2.48, *SE* = .55, *df* = 756.15, *t* = -4.53, *p* < .001, *CI* = -.356 to -1.40; 1.04) as well as an individual's recall of the previous night's SOL (*Estimate = -2.52*, *SE* = .61, *df* = 710.41, t = -4.11, *p* < .001, *CI* = -3.72 to -1.32; 2.40). More positive valence in the morning was associated with shorter time taken to fall asleep each evening. More negative valence in the morning was associated with longer time taken to fall

asleep in the evening. Additionally, morning valence and evening valence together predicted SOL. In comparison, morning valence is a stronger predictor of the subsequent night's SOL than it is of the prior night's SOL.

The findings from Hypothesis One offer knowledge about how emotion impacts sleep. First, an individual's SOL is impacted by their morning perception of how their emotional arousal changed overnight from pre-sleep to post-sleep. In a healthy sample of adults, SOL is perceived to be impacted by pre-sleep emotion, independently by evening emotional arousal, evening emotional valence, and by the evening interaction between emotional arousal and emotional valence (Table 4). The impact of one's evening perception of how their emotional arousal has changed across the whole is less important than valence for efficient sleep onset.

Hypothesis Two: Sleep Predicting Emotion

Five out of eight (5/8; 62.5%) possible impacts of sleep quality on emotion dimensions were statistically significant (Table 7). Supporting Hypothesis Two, better sleep quality predicted more positive morning valence the subsequent morning (*Estimate* = .58, *SE* = .06, *df* = 776.17, t = 10.09, p < .001, *CI* = .47 to .70; .23), while poorer sleep quality predicted more negative valence the subsequent morning. Better sleep quality also predicted more positive valence the subsequent night (*Estimate* = .23, *SE* = .07, *df* = 773.54, t = 3.43, p = .001, *CI* = .10 to .36; .26), while poorer sleep quality predicted more negative valence the subsequent night. In combination, these findings indicate that sleep quality predicts directionality of valence the endures throughout wakefulness. When emotional change scores were examined, better sleep quality predicted shift toward negative valence across wakefulness, that is from morning to evening (*Estimate* = -.32, *SE* = .07, *df* = 528.344, t = -4.86, p < .001, *CI* = -.45 to -.19; .26). Better sleep quality also predicted shift toward positive valence overnight across the sleep-wake

transition, from evening to morning (*Estimate* = .36, *SE* = .07, *df* = 339.52, *t* = 5.24, *p* < .001, *CI* = .22 to .49; .27). As seen by comparison of confidence interval window widths, sleep quality has relatively equivalent impacts on next-day valence timepoints, with strongest impact on next-morning valence.

For comparing and contrasting with these valence based findings, the other circumplex dimension—emotional arousal—was also examined as impacted by sleep quality. Better sleep quality predicted lower post-sleep morning arousal (*Estimate* = -.21, *SE* = .06, *df* = 780.99, *t* = -3.40, *p* = .001, *CI* = -.33 to -.09; .24) while poorer sleep quality predicted higher post-sleep emotional arousal. After a poor night's sleep, morning emotion was thus characterized by higher arousal and negative valence. After a good night's sleep, morning emotion was characterized by lower arousal and positive valence. Sleep quality did not predict change in emotional arousal across the day nor overnight. There were no statistically significant interactions between sleep quality and emotional interplay. Together, findings related to sleep-emotion directionality of Hypothesis Two indicate that sleep quality predicts linearity toward morning emotional arousal whereas sleep quality more comprehensively predicts emotional valence across the 24-hour cycle.

Hypothesis Three: Insomnia Severity Moderating Sleep-Emotion Integration

Insomnia severity is examined first as a moderator operating emotion-sleep directionality (Hypothesis 3a) and then as a moderator operating sleep-emotion directionality (Hypothesis 3b). Hypothesis 3a was supported in that insomnia interacted with emotional arousal. Insomnia severity interacted with evening-to-morning change in emotional arousal to predict SOL (*Estimate* = -.38, *SE* = .08, *df* = 660.05, *t* = -4.89, *p* < .001, *CI* = -.53 to -.22; .31; Figure C), suggesting overnight predominancy of change in arousal as a trigger of an emotion-sleep

reaction. Insomnia severity did not interact with morning-to-evening change in emotional arousal to predict SOL. This distinction suggests that one's perception of SOL is influenced by morning perception of the previous night, as overnight retrospective memory. The statistically significant main effect of evening-to-morning change in arousal on SOL remained even when its interaction with insomnia was included in the model. This finding is consistent with the findings reported under Hypothesis One, suggesting that one's emotional state influences one's retrospective memory of time spent trying to fall asleep last night.

Hypothesis 3b was supported in that positive valence in the morning and positive valence in the evening each were associated with insomnia severity. Morning valence and evening valence exhibited moderate association with each other ($r = .53$, $p < .001$). Insomnia severity exhibited mild inverse association with morning valence ($r = -.28$, $p < .001$) and with evening valence ($r = -.22$, $p < .001$). Lower levels of insomnia predicted more positive valence in the morning as well as in the evening, whereas higher levels of insomnia predicted more negative valence in the morning as well as in the evening. Suggesting valence predominance in the link between insomnia and emotion, there was not a link between insomnia and arousal in the morning nor in the evening. While morning arousal and evening arousal exhibited moderate association with each other ($r = .48$, $p < .001$), neither of them were associated with insomnia severity. These are the findings of how insomnia severity relates to Hypotheses One and Two. Within Hypothesis Three, insomnia severity is examined in a few different ways: first examined as a categorical predictor of sleep-emotion relationships and next as a continuous predictor that interacts with the sleep-emotion circumplex over time.

Insomnia as a categorical predictor of sleep-emotion relationship. Categorically at the highest quartile of insomnia severity scores (22-28), morning arousal and evening arousal were

more strongly associated with each other ($r = .65$, $p < .001$), compared to their smaller association with each other ($r = .48$, $p < .001$) at the lower three categories of insomnia severity (0-21). At the highest quartile of insomnia severity scores (22-28), morning valence and evening valence were not associated, whereas at the lower categories of insomnia severity (0-28) morning valence and evening valence were moderately associated ($r = .54$, $p < .001$). At the highest quartile of insomnia severity scores (22-28), morning valence and morning arousal were not associated with each other. Within the non-severe quartiles (0-21), morning valence and arousal were correlated ($r = -.16$, $p < .001$) while evening valence and arousal were correlated ($r = .23$, $p < .001$), demonstrating circumplex interplay at each timepoint. Morning arousal and evening valence were associated ($r = -.12$, $p = .001$), and morning valence and evening arousal were associated ($r = -.103$, $p = .004$), within the non-severe quartile. Individuals reporting clinical severity of insomnia experienced (a) disjointedness of circumplex emotion dimensions in the morning and (b) inconsistency in valence of emotion across wakefulness.

Insomnia as a continuous predictor of sleep-emotion relationship. Continuous moderation of insomnia severity on these relationships core sleep-emotion relationships were then tested. Several interaction effects related to insomnia severity emerged. The effect of evening-to-morning arousal on SOL varied as a function of insomnia (*Estimate* = -.38, *SE* = .08, *df* = 670.37, $t = -5.02$, $p < .001$, *CI* = -.53 to -.23; .30; Figure C). This indicates that the overnight trajectory of emotional arousal changes direction depending on level of insomnia severity. Moreover, the effect of evening arousal on SOL varied as a function of insomnia (*Estimate* = -.28, *SE* = .08, *df* = 741.78, $t = 3.29$, $p = .001$, *CI* = .13 to .46; .33; Figure D). The effect of morning valence on SOL also varied as a function of insomnia (*Estimate* = -.28, *SE* = .08, *df* = 718.10, $t = -3.51$, $p < .001$, *CI* = -.44 to -.12; .32; Figure E). These singular emotion

findings indicate that the relationship between insomnia and SOL is intensified by the evening timepoint of the arousal dimension of the circumplex model, as well as by the morning timepoint of the valence dimension of the circumplex model.

With emotion-to-sleep direction, insomnia also interacted with several variables to predict sleep quality. The effect of morning arousal on recent sleep quality rating varied as a function of insomnia (*Estimate* = .01, *SE* = .00, *df* = 759.32, *t* = 2.63, *p* = .009, *CI* = .00 to .01; .01; Figure I). The effect of evening valence on that night's sleep quality also varied as a function of insomnia (*Estimate* = =.01, *SE* = .00, *df* = 770.30, *t* = -1.98, *p* = .048, *CI* = -.01 to -.00; .01; Figure G). Insomnia also interacted with several emotion variables to predict sleep quality. The effect of morning arousal on recent sleep quality rating varied as a function of insomnia (*Estimate* = .01, *SE* = .00, *df* = 759.32, *t* = 2.63, *p* = .009, *CI* = .00 to .01; .01; Figure F). The effect of evening valence on that night's sleep quality also varied as a function of insomnia (*Estimate* = =.01, *SE* = .00, *df* = 770.30, *t* = -1.98, *p* = .048, *CI* = -.01 to -.00; .01; Figure G). These insomnia severity impacts were demonstrated with the directionality of emotion affecting sleep. Both emotional arousal and emotional valence impacted SOL, in their correlated interactions *and* with distinct independent variance impacting SOL.

Insomnia related impacts with sleep as the predictor were tested, representing interactive directionality of sleep affecting emotion. Insomnia interacted with sleep quality to predict morning arousal (*Estimate* = .02, *SE* = .01, *df* = 780.16, *t* = 2.74, *p* = .006, *CI* = .01 to .04; .03; Figure F), evening-to-morning arousal (*Estimate* = .02, *SE* = .01, *df* = 556.70, *t* = 2.10, *p* = .036, *CI* = .00 to .04; .04; Figure G), and morning-to-evening arousal (*Estimate* = -.02, *SE* = .01, *df* = 621.72, *t* = -2.01, *p* = .045, *CI* = -.04 to -.00; .04; Figure H). These findings indicate that the effects of sleep quality on emotional arousal are dependent of insomnia status. As a reminder,

when insomnia was not included in the model, sleep quality hardly predicted emotional arousal yet predicted emotional valence to a greater degree with robust influence across time. As seen by comparison of confidence interval window widths, insomnia severity has relatively equivalent and strong impacts on a variety of sleep-emotion integrative relationships.

Discussion

The current EMA study is novel in demonstrating that components of emotional arousal, emotional valence, sleep-wake transition, and wake-sleep transition exhibit powerful integration patterns on their own and in the context of insomnia. Within the general population, rising levels of insomnia severity is cause for concern (Kessler et al., 2011; Morin, 2003; Morin et al., 2014) and there is a need to broaden and extend the ability to conceptualize insomnia experiences from a variety of angles. A novel finding is that the emotion circumplex model, which articulates the intersection between emotional arousal and valence, exhibits close relationships with specific sleep parameters and insomnia severity. Emotional arousal and valence each were found to predict SOL, but not to predict sleep quality. Reciprocally however, sleep quality was found to predict emotion. Sleep quality is considered a mechanism of psychological health in its prediction of positive emotional valence. Additionally, inverse association between emotional arousal and valence was found in the morning and in the evening, as a hallmark of healthy emotional oscillation. Finally, the modal self-reported indicator of psychological health in the sample is moderate valence and low arousal at both pre-sleep and post-sleep pillars of subjective experience. Overall, the current EMA study support research using the circumplex framework or foundation to advance emotion-sleep research. Our study is the first to use multilevel lagged regressed change score statistical modeling to investigate core reciprocal impacts of sleep and emotion, mapped alongside a gradient of insomnia severity.

Study findings are considered in the context of the existing scientific literature. This section first discusses the results in order of hypotheses, describing how results fit the aims of the study linked to the extant literature. The overall findings demonstrate that different types of subjective pattern exists with nested structure: self-reported experiences of emotion and sleep, nested within individuals, nested within between-subject insomnia severity. The circumplex emotion-sleep integration model is then discussed as relevant to assessment of insomnia, interventions for insomnia, and future research directions.

Emotion Predicting Sleep

Examining how emotion predicts sleep (Hypothesis One), both arousal and valence dimensions of the emotional circumplex predicted SOL. The strongest association of emotional arousal on SOL was the evening-to-morning change from lesser-to-greater arousal. To a similar degree, prior morning valence and next-morning valence predicted SOL. Next, in descending order, the strongest predictors of SOL were same-night's evening arousal, the same-night's evening valence, and the next-night's evening arousal was the weakest predictor. In the evening, the interaction between valence and arousal also predicted SOL. In sum, data demonstrates granular components contributing to emotion-sleep-emotion directionality. These findings extend research (Bouwmans et al., 2017; de Wild-Hartmann et al., 2013) by demonstrating with EMA design that pre-sleep emotional arousal and valence impact sleep experience. Emotion dimensions may interact in service of facilitating ease of falling asleep. Interestingly, in contrast to the impact of emotion on SOL, there is a different relation with sleep quality. In considering directional impacts of emotion on sleep quality, it is notable that wakeful emotion does not predict subsequent sleep quality in any model. Instead, sleep quality is a powerful predictor of wakeful emotion.

Sleep Predicting Emotion

Further along the cycle, as presented by the second hypothesis, sleep quality predicted both dimensions of the emotional circumplex in the morning. Better sleep quality predicted more positive valence in the morning and increased arousal in the morning. Poorer sleep quality predicted more negative valence in the morning and decreased arousal in the morning. Additionally, in the morning arousal and valence were inversely related, irrespective of sleep quality. These findings indicate that sleep quality independently predicts each emotional dimension, valence and arousal. In the morning, positive emotional dimensions buffer against negative valence, independent of sleep quality.

Sleep quality is a core construct involved in determining subsequent wakeful valence. There has been debate and confusion in the literature about how sleep quality impacts valence. When modeled orthogonally (as with the PANAS; Lang, 1980), poor sleep quality has been associated with more negative valence as well as with less positive valence. Rather than assessing positive valence and negative valence on two orthogonal continua as is common (e.g., Bouwmans et al., 2017; Shen, van Schie, Ditchburn, Brook, & Bei, 2018; Kalmbach et al., 2014; Wong et al., 2021), it seems to have contributed inconsistent and incongruent results across studies. A circumplex dimensional metric is more conducive to modeling how emotional states arise change over time.

Our findings corroborate past research indicating that greater sleep quality has a buffering effect on emotional well-being such that it encourages greater positive emotion and less negative emotion (Wichers et al., 2007). Further, a ratio of higher positive emotion to lower negative emotion is a definitional component of emotional well-being (Kahn et al., 2013; Vulpe & Dafinoiu, 2011). Testing the emotional circumplex model, the current EMA study demonstrates

presence of a buffering spectra of valence wherein a valence rating is seen to reflect one's momentarily appraised pleasantness or unpleasantness of mixed emotional experience. Our results suggest that better sleep quality assumes a ratio of relatively more positive than less negative valence, and that sleep is involved in its stabilization across time. Good sleepers show a positively biased valence ratio whereas poor sleepers show negative bias, and the positive bias of good sleepers tends to intensify with sleep restriction (Gerhardsson et al., 2017).

In the current EMA study, people with more negative morning valence exhibited a positive association between insomnia severity and SOL (Figure E). Early in the sleep onset period, the effect of wakeful positive valence on SOL varies as a function of insomnia. However, people reporting more consistent positive morning valence do not experience such close connection between insomnia severity and SOL. Stability of positive valence contributes to a weakened relationship between insomnia severity and SOL each night. A weakened relationship suggests that it is more vulnerable to break down or disintegration, such that people with positive valence do not generalize their nights of delayed sleep onset to generalize to insomnia severity. When individuals experience negative valence, there is a stronger relationship between insomnia severity and SOL, perhaps reflecting the etiological component of negative valence involved in insomnia. This finding is contextualized within past research using the ISI. For healthy people with relatively low ISI scores, shortened sleep predicted a reduced bias to positive stimuli (Vargas et al., 2017).

Statistically Significant Interactions

Our interaction findings fill lacunae in the insomnia literature by identifying circumplex emotional interplay patterns, as well as insomnia related patterns that contribute to altered emotional perception related to sleep quality and onset (Kyle et al., 2014). Interaction effects

(Figures A-J) indicate directionality of sleep-emotion relationships, further moderated by insomnia severity. These interaction effects are illustrated first in their wakeful emotional interplay at each timepoint and then in their sleep-emotion integrative interplay as driven by insomnia severity.

Two statistically significant interaction effects occurred reflecting circumplex emotional interplay related to sleep (Figure A-B). Individuals who tended to experience more regular negative valence also experienced an inverse association between positive valence and SOL. As the sleep onset period progressed, there seemed to be an intensification of this interaction experience, for people with more negative valenced cognitive frames (Harvey et al., 2002). A synergistic valence interaction also occurred across the day to predict SOL (Table 6). These finding are novel in demonstrating core components of how emotional circumplex interplay and the sleep inform each other in healthy populations.

Six statistically significant interaction effects occurred as a function of insomnia (Figures C-J). As the number of minutes taken to fall asleep increases (Figures C-E), an individual becomes sensitive to forming predominant pairings integrating sleep and emotion variables. Individuals with high levels of insomnia severity exhibit a negative association between evening-to-morning arousal and SOL (Figure C). A longer sleep onset period is associated with the experience of having heightened arousal in the evening and minimal arousal in the morning; a steeper negative slope of overnight change. This is an important finding to apply to insomnia research and the study of perception of time for well-being.

Our findings about perception of one’s SOL are considered in earnest as minutes taken to fall asleep are modeled in several of the interaction effects referenced above (Figures A-E). Harvey and Tang have found and replicated the finding that misperception of minutes taken to

fall asleep is actually not an issue for individuals with insomnia (Harvey & Tang, 2011; Tang & Harvey, 2005), debunking a common misconception that time misperception is a core issue in insomnia. As such, we take at face value our participants' estimated nightly timepoints that it reportedly took to fall asleep, particularly as related to emotional arousal. Given that SOL and pre-sleep arousal have robust associations (Hoyniak et al., 2021), and cognitive pre-sleep arousal and psychophysiological arousal are the two types of pre-sleep arousal most often studied in relation to insomnia. Schmidt and Van der Linden (2013) have since found that emotional arousal is an issue involved insomnia with impacts that extend beyond the issue of cognitive arousal.

Our findings demonstrated that pre-sleep emotional arousal is closely tied to the timing of the sleep onset period. Several subjective interaction effects emerged early in the sleep onset period, moderated by insomnia severity. Individuals tended to experience close connection between their evening arousal and the time it took them to fall asleep that night. Starting early in the sleep onset period, longer SOL was associated with worse insomnia severity especially for people who more consistently experience negative valence than those with positive valence. These findings indicated that insomnia severity is a driver of pre-sleep emotional arousal and wakeful emotional valence, with interaction effects contributing to SOL timing.

At high levels of insomnia severity, our data shows increased power of relationship between emotional arousal and sleep. There is a strong inverse association between evening-to-morning arousal and sleep quality (Figure I), and there is a strong positive association between morning-to-evening arousal and sleep quality (Figure J). Depending on whether or not insomnia severity was included in the model, sleep quality was related to a different dimension of the circumplex emotion model. As a core mechanism of insomnia (Harvey et al., 2008) and

described above, sleep quality predicted cyclical valence patterns when time was the only other predictor in the model. However, when insomnia severity was entered in the model, sleep quality more robustly predicted emotional arousal. Evening valence was also seen to predict sleep quality. These findings corroborate and extend results in the sleep and insomnia literature.

Components of the Cycle

Our findings suggest that the etiology of insomnia involves reformation or reconstruction of subjective emotional cycles across wake-sleep-wake intervals of consciousness. When not including insomnia severity moderation in the model, idiographic representation was characterized by a 10-component cycle, wherein sleep quality inextricably predicted emotional valence (Table 2). The number of components refers to the number of statistically significant predictors and outcomes that emerged. Pre-sleep arousal and valence independently and synergistically predicted SOL (Table 3). It is noteworthy that a different number of subjectively interconnected components emerged depending on whether insomnia severity was included in the self-representational model (Table 2 & Table 3). The differential numbers of components suggest that the insomnia severity gradient coincides with truncation of a perceived cycle.

A 7-component cycle represented how sleep-emotion relationships were moderated by insomnia severity, wherein evening arousal and evening valence predicted SOL and sleep quality, respectively. Evening-to-morning change in arousal predicted SOL and sleep quality. Sleep quality in turn predicted overnight arousal, next-morning arousal, and next-day morning-to-evening arousal. Emotional arousal overall was more involved in sleep-emotion integration with involvement if insomnia severity (Table 3). Without involvement of insomnia severity, emotional valence was more involved in sleep-emotion integration (Table 2). These findings indicate that the circumplex manner through which experience is integrated differs depending on

one's gradient of experience with insomnia.

Two component similarity was found between the models as well. The two predictive processes that emerged in both models (Table 2 & Table 3) were that evening emotional arousal predicts SOL and that sleep quality predicts next-morning emotional arousal. Emotional arousal predicted SOL in the healthy (10-component) model These two relationships may endure across insomnia experiences as related to mental disorders (Swinkels et al., 2013). Another notable finding was seen in self-representation of the sleep phase. Within the healthier sleep representational model, sleep onset latency predicted sleep quality (Table 2). Within the insomnia model, sleep onset latency did not predict sleep quality (Table 3). This corroborates literature demonstrating that insomnia severity, broadly, is associated with fragmentation throughout the sleep period. This is displayed as the digression between the healthy model (Table 2) and the insomnia severity model (Table 3), such that individuals with insomnia severity do not experience continuity or relationship between SOL and sleep quality.

Synthesis of the Literature and Future Direction

The theory behind these findings are considered to stem originally from personality research by Kales and colleagues (1976)—who identified a role of emotion dysregulation in insomnia—proposing an internalization of conflicts model. In the self-representational "introjective" model, insomnia experience was seen to predispose one to internalize psychological challenges, leading to heightened levels of emotional arousal that contributed to the individual's inability to sleep. Since then, there have been few attempts to build upon theory of emotional components with continuity. Across the decades it seems that the field has placed the proverbial cart before the horse in attempting to study emotion labels before a core framework of emotion was first established. Chronologically coinciding in wakefulness research,

Russel (1980) coined the emotional circumplex. Nearly half a century later, the current EMA study integrates these empirical viewpoints. The current EMA study is a step forward toward illustrating how the foundational circumplex model is built upon in studying additional biopsychosocial factors of well-being (Posner et al., 2015).

Looking toward the future of sleep-emotion research, the current EMA study encourages scholars to continue building upon the cyclical circumplex model. Two main limitations of the current EMA study are noted. The first is that data collected was self-report or survey data and therefore do not reflect biological or physical correlates of the sleep-emotion cycle. Within the extant literature there is a relative dearth of research comparing psychophysiological variables and emotional valence variables (Bacaro et al., 2020; Baglioni et al., 2010; Wassing et al., 2019). The research knowledge base would benefit from ongoing research aimed at integrating psychological and biological variables to better understand the sleep-emotion cycle. Future research could supplement self-report emotion measurement with objective measures of sleep variables, such as actigraphic and polysomnographic assessments. The second limitation is that the study sample of adults in the United States completing an online naturalistic study cannot extend to youth populations nor to geographical contexts outside of the United States. Future research would benefit from ongoing study of idiographic differences and similarities in how circumplex emotion dimensions operate across cultures (De Vaus et al., 2018; Kuppens et al., 2017; Ogunbode et al., 2021), as related to sleep. Beyond these limitations and general future directions, we encourage two areas of further research: dynamics of emotional static and change, and the role of the dominance dimension in the sleep-wake circumplex cycle.

Dynamics of Emotional Static and Change

Our current study focused on quantifying emotional experience without narrowing the

construct of experience through linguistic labels. The results found in the current EMA study suggests that use of the SAM non-verbal measure is an asset to detecting patterns of sleep-emotion integration (Appendix B). Emotion is known to be a difficult construct to operationalize in a fluid yet stable manner (LeDoux, 2012). It is defined as a change over time process triggered in part by internal and external stimulation and characterized by a valence component, a specification unique to the definition of *emotion* as opposed to *affect* (Baglioni et al., 2010). This specification is important to hold in mind when conceptualizing how feelings are represented, and how their representation changes over time to pursue of fitness-maximizing goals (Guitar et al., 2020; Nesse & Ellsworth, 2009), such as the evolutionarily grounded goal to achieve sleep and benefit from sleep on a regular basis. Emotions play an integral role in psychological operations of all mental processes, critical to the evolution of consciousness (Izard, 2009). Emotion is valuable to the study of sleep-wake well-being.

Emotional valence and emotional arousal operated inversely with each other, at pre-sleep and at post-sleep. Each emotional dimension had a specific theme of relationship to SOL and sleep quality, disparate from each other yet related to each other. Evidence suggesting that pre-sleep arousal accounts for a significant amount of variance in sleep is further corroborated. While past research has demonstrated that pre-sleep arousal predicts sleep broadly (Morin et al., 2004; Tousignant et al., 2019; Winzeler et al., 2013), this is the first published study to disentangle and differentiate impacts of pre-sleep emotional arousal on SOL compared to sleep quality. It also is the first study to test circumplex interaction effects that predict sleep.

Regarding emotion-sleep directionality, emotional arousal was found to operate through interactive interplay with emotional valence in the pre-sleep period. It demonstrated that pre-sleep circumplex interaction sparked change in SOL but did not impact sleep quality. The only

singular emotion variable that predicted sleep quality was found in the insomnia model. Pre-sleep emotional valence predicted sleep quality, and overnight change in arousal predicted sleep quality (Table 3). This suggests that insomnia development is associated with coupling between pre-sleep valence and sleep quality, whereas healthy emotional oscillation is associated with coupling between sleep quality and post-sleep valence. This demonstrates directional nuance.

Sleep quality primarily operates as a predictor in the healthy sleep-emotion cycle; it is an especially powerful predictor of emotional valence and its stability. These findings about and sleep quality predictions of valence have implications within wakeful emotion research (Gruber et al., 2013) that may extend to sleep-wake research. Positive emotion stability is associated with better psychological health, whereas variability in positive emotion is associated with poorer psychological health (Gruber et al., 2013). In the current EMA study context of emotion driven sleep-wake pattern, consistently positive emotional valence was associated with lower insomnia severity.

Emotional dynamics are considered in context of how they support well-being through sleep. High emotional inertia of valence is defined by valence stability from moment to moment, relatively impervious to internal and external influences (Kuppens et al., 2011). With the current EMA study results in mind, one can imagine that high inertia of positive emotional valence might be associated with good sleep whereas high inertia of negative emotional valence might be associated with more insomnia severity. Low emotional inertia of valence, defined as instability in valence swayed more easily by internal and external stimuli, might also be associated with insomnia severity. These hypotheses have yet to be tested. Future research could compare how static and stable patterns of emotional inertia for each circumplex dimension are involved in the development of or recovery from insomnia. Ample opportunities exist to replicate our model,

testing its integrity and form (Appendix C) across a variety of contexts.

Dominance Dimension and Social Process

Wakefulness research has modeled the emotional circumplex with a third dimension, social dominance (Bradley & Lang, 1994; Jerram et al., 2014; Russell & Mehrabian, 1974). The social area of emotional circumplex is useful for understanding how emotions are conveyed and processed between individuals (Guadagni et al., 2017). While the current EMA study prioritizes modeling the emotional arousal and valence intrapsychic variables, next steps will include examining a tri-axis circumplex model adding a third interpersonal variable to depict individual experience. As such, it seems such that emotional valence and arousal operate more introjectively as emotion, whereas the dominance or control dimension operates in the transition from internal to external observable affect. There is strong research indicating that the dominance dimension captures an element of emotional experience above and beyond that which is captured by emotional arousal and valence (Imbir, 2016). As sleep, emotion, and interpersonal processes have been found to be related (Nowack, 2017), future research modeling their co-occurrence and co-operation will offer new insight.

Clinical Implications and Intervention Opportunities

Within the clinical literature, insomnia and the disadvantageous regulation of emotion have been broadly identified as two potential transdiagnostic processes, each varying along a continuum ranging from healthy levels to dysfunctional levels evidenced across mental disorders (Harvey et al., 2011; Fairholme et al., 2013; Fairholme & Manber, 2015). The ISI is a sleep measure that is particularly conducive to clinical application (Seow et al., 2018), indicating a promising degree of generalizability of the current EMA study findings. Within the insomnia literature, sub-clinical levels of insomnia often co-occur within a variety of clinical disorders,

and episodic insomnia issues can manifest alongside increased stress of daily living (Harvey, 2002; Tousignant et al., 2019). Future research could hone the literature on how emotional components operate in the contexts of co-occurring insomnia and anxiety with depression. This is a fruitful direction as anxiety and depression are also shown to progress in co-occurrence with insomnia components (de Wild-Hartmann et al., 2013; Kalmbach et al., 2014; Kalmbach et al., 2021). Constructed emotional processes are key variables for sleep and well-being research, as emotional disorder and insomnia disorder are known to underlie psychologically transdiagnostic processes and symptoms (Barlow et al., 2018; Fairholme et al., 2013; Kalmbach et al., 2021). In totality, the emotional circumplex model is worth incorporating into research.

The efficacy of cognitive behavioral therapy for insomnia (CBTi) could be enhanced by incorporating intervention strategies that address emotional processes (Baglioni et al., 2010; Kyle et al., 2014), such as using cyclical sleep reinforcement to enhance reward learning (Gocke et al., 2020; Tamaki et al., 2020) or tailoring skills-building to target cognitive inhibition deficits seen in insomnia treatment (Ballesio et al., 2019) A dissection of how our results could relate to the components of CBTi, as operationalized by dismantling designs (Bramoweth et al., 2020; Maurer et al., 2020), is beyond the scope of the current manuscript. Instead, some general ideas are proposed about intrapsychic processes that could be useful for encouraging optimal emotion-sleep regulation. The first is to encourage increased mindfulness and behaviors focused on addressing disadvantageous emotion fluctuation patterns. Studies on mindfulness interventions for sleep have demonstrated that experiential focus on the present moment and present experience is essential for good sleep. In the pre-sleep period, mindful focus on present experience is invaluable for efficient sleep onset. Cognition based arousal like rumination and worry relate to insomnia (Harvey et al., 2005; Harvey & Greenall, 2003; Jansson & Linton,

2006; Zawadzki, 2015) but emotional arousal components have been underexplored.

The current EMA study is the first to find that emotional arousal components of constructed experience closely relate to insomnia severity, and suggest that the emotional arousal component also may be involved in the development of insomnia (Tables 2 and 3). To our knowledge, this is also one of the few studies to investigate the operation of the valence component in sleep related well-being (Ong et al., 2017). Bolstering the state of the literature on healthy emotion fluctuation and sleep-wake integration, our findings specify and confirm that sleep quality predicts stability of emotional valence, whereas insomnia severity predicts instability of emotional circumplex integration. Our results are considered alongside recent research demonstrating that people with good sleep perceive stimuli to have more negative valence and more emotional arousal following sleep deprivation, than do their counterparts with poor sleep (Zhang et al., 2019). Individual differences exist depending on the sleep success one perceives one's self to have. Depending on one's level of insomnia along a severity gradient, there seem to be individual differences in which relationships one detects between components of sleep and emotion. People who generally sleep well seem to be more sensitive to when their emotional experience is off baseline, perhaps because sleep issues are more aversive when novel or unexpected. In comparison, individuals experiencing high insomnia severity may be more habituated to being off-kilter from what they perceive to be their baseline patterns in sleep-emotion cyclicity.

Conclusion

In sum, the current EMA study demonstrates specific integration pattern between circumplex emotion and sleep components, constructed as a cycle. Overall, results of the current EMA study are consistent with research demonstrating reciprocal relation between sleep and

emotion variables (Babson and Feldner, 2015). Extant evidence is advanced by several novel findings of the current EMA study. As insomnia severity was represented in subjective experience, one's self-perception of the cycle narrowed. Cyclical narrowing was evidenced as modification from a healthier 10-component self-perceptual cycle to an insomnia based 7-component self-perceptual cycle. Broadly in the 10-component cycle of health (Table 2), sleep quality predicted wakeful valence; in the 7-component cycle of insomnia, sleep quality predicted wakeful arousal (Table 3). The insomnia gradient is therefore considered to augment how an individual understands their sleep as informing their emotional experience. This finding is related to directional pattern during the sleep-wake transition. Another novel finding emerged related to directional pattern during the wake-sleep transition. In the healthier 10-component cycle, evening arousal and evening valence independently and in conjunction predicted SOL, but they did not sleep quality. In the 7-component insomnia cycle, evening arousal primarily predicted SOL whereas evening valence primarily predicted sleep quality. This finding suggests that integrative conceptualization of how emotion informs sleep differs and should be considered as having idiographic influence rather than broad stroke influence. Overall, the current EMA study moves the field forward in contextualizing incongruent findings from the multitude of limited study designs and definitional inconsistencies found in the extant literature (Babson & Feldner, 2015; Pressman & Cohen, 2005). It further specifies idiographic circumplex patterns that exist in the context of sleep. The quality and rigor of the current EMA study design and results about sleep, emotion, and insomnia contribute to a growing knowledge base in the psychological science discipline.

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Tables

Table 1

Intercorrelations for Sleep-Emotion Variables

Variable	1	2	3	4	5	6
1. MorningValence	**-**	**-.150****	**.532*****	-.095**	**-.192*****	**.450*****
2. MorningArousal		-	**-.110****	**.484*****	-0.026	**-.168*****
3. EveningValence			**-**	**-.214*****	**-.168*****	**.274*****
4. EveningArousal				**-**	.082*	**-.149*****
5. CSDDAILY_3SOLminREDO					**-**	**-.209****
6. Sleep Quality						**-**

Note. The results for the full sample (n = 799) are shown in Table 2. SOL = sleep onset latency.
Bold indicates statistical significance after Bonferroni correction [.05 divided by 6 < .008] as threshold for p-value.*p < .05. **p < .01. p*** < .001.

Key for Table 2 and Table 3
Blue = present in Table 2 and not Table 3
Green = present in Table 3 and not Table 2
Purple = present in both Table 2 and Table 3

TABLE 2

Multilevel Lagged Regressed Change Analysis Reflects Sleep-Emotion Integration as 10-Step Cyclical Change

Step of Cycle	Predictor	Outcome	*B*	*SE*	*t*	*p*	95% CI
1	Evening Arousal	SOL	1.90	0.59	3.21	<.001	[.70, 3.1]
2	Evening Valence	SOL	-1.79	0.58	-3.06	.002	[-2.9, -.64]
3	SOL	EM_Arousal	-0.01	0.00	-3.91	<.001	[-.01, -.00]
4	SOL	Sleep Quality	-0.00	0.00	-2.92	.004	[-.01, -.00]
5	SOL	Next-Morning Valence	-0.01	0.00	-3.714	<.001	[-.01, -.00]
6	Sleep Quality	EM_Valence	0.36	0.07	5.24	<.001	[.22, .49]
7	Sleep Quality	Next-Morning Valence	0.58	0.06	10.09	< .001	[.47, .70]
8	Sleep Quality	Next-Morning Arousal	-0.21	0.06	-3.39	.001	[-.33, -.09]
9	Sleep Quality	Next-Evening Valence	0.23	0.06	3.43	.001	[.10, .36]
10	Sleep Quality	Next-day ME_Valence	-0.32	0.07	-4.87	<.001	[-.45, -.19]

Note. Statistically Significant Results of Within-Participant Lagged Regressed Change Analysis. *B* = *un*standardized regression coefficient; *CI* = confidence interval; LL = lower limit, *UL = upper limit*; *SE B* = the standard error of the unstandardized regression coefficient. ME_Valence = morning-to-evening change in valence; EM_Valence= evening-to-morning change in valence; ME_arousal = morning-to-evening change in arousal; EM_Arousal = evening-to-morning change in arousal; SOL = sleep onset latency in minutes.

Key for Table 2 and Table 3
Blue = present in Table 2 and not Table 3
Green = present in Table 3 and not Table 2
Purple = present in both Table 2 and Table 3

TABLE 3

Multilevel Lagged Regressed Change Analysis: Insomnia Moderates Sleep-Emotion Integration as 7-Step Cyclical Change

Step of Cycle	**Predictors**	**Outcome**	***B***	***SE***	***t***	***p***	**95% CI**
Insomnia Interacting with..							
1	Evening Arousal	SOL	0.29	0.08	3.49	.001	[.13, .46]
2	Evening Valence	Sleep Quality	-0.01	0.00	-1.98	.048	[-.01, -.00]
3	EM_Arousal	SOL	-0.38	0.08	-5.02	<.001	[-.53, -.23]
4	EM_Arousal	Sleep Quality	-0.38	0.08	-5.02	<.001	[-.53, -.23]
5	Sleep Quality	EM_Arousal	0.02	0.01	2.10	.036	[.001, .044]
6	Sleep Quality	Next-Morning Arousal	0.02	0.01	2.74	.006	[.01, .04]
7	Sleep Quality	Next-day ME_Arousal	-0.02	0.01	-2.01	.045	[-.04, -.00]

Note. Statistically Significant Results of Multilevel Lagged Regressed Change Analysis. *B* = *un*standardized regression coefficient; *CI* = confidence interval [lower limit, upper limit]; *SE* = standard error of the unstandardized regression coefficient; t = t-statistic; p = p-value. ME_Valence = morning-to-evening change in valence; EM_Valence= evening-to-morning change in valence; ME_arousal = morning-to-evening change in arousal; EM_Arousal = evening-to-morning change in arousal; SOL = sleep onset latency in minutes.

TABLE 4

Impacts of Emotion Dimensions on SOL

Predictor	Outcome	*p-value*	*CI Difference*	Predictor	Outcome
Statistically Significant Findings				***Non-Statistically Significant Findings***	
Evening-to-morning change in arousal (-)	Interim SOL	$p < .001$	2.07	Morning-to-evening change in arousal	Next SOL
Morning Valence (-)	Previous SOL	$p < .001$	2.40	Morning-to-evening change in valence	Next SOL
Morning Valence (-)	Next SOL	$p < .001$	1.04	Evening-to-morning change in valence	Interim SOL
Evening Arousal (+)	Same SOL	$p = .001$	2.32	Morning Arousal	Previous SOL
Evening Valence (-)	Same SOL	$p = .002$	2.30	Morning Arousal	Next SOL
Evening Arousal (+)	Next SOL	$p = .013$	2.26	Evening Valence	Next SOL

Note. Sign of (+) indicates positive association and sign of (-) indicates negative association. CI Difference = the absolute value of the confidence interval margin; a smaller absolute value score indicates greater statistical significance. SOL = Sleep onset latency. Interim SOL = the sleep onset period that occurs between an evening and the next morning.

TABLE 5.

Evening Circumplex Interplay Predicting SOL

	Estimate	***SE***	***df***	***t***	***p***	***95% CI***	
						Lower Bound	Upper Bound
Intercept	18.13	1.79	106.80	10.14	<.001	14.59	21.67
Evening Valence	-1.25	0.59	748.57	-2.11	.036	-2.42	-0.08
Evening Arousal	1.59	0.59	743.74	2.68	.008	0.42	2.76
Evening Valence x Arousal Interplay	-0.73	0.24	768.83	-3.02	.003	-1.20	-0.26

TABLE 6.
Across-Day Valence Interplay Predicting SOL

	Estimate	***SE***	***df***	***t***	***p***	**95% CI**	
						Lower Bound	Upper Bound
Intercept	17.66	1.76	118.63	10.06	<.001	14.18	21.13
Morning Valence	-2.04	0.65	748.02	-3.12	.002	-3.32	-0.76
Evening Valence	-1.14	0.60	753.77	-1.90	.058	-2.32	0.04
Morning Valence x Evening Valence Interplay	0.52	0.26	753.18	2.01	.045	0.01	1.03

TABLE 7

Impacts of Sleep Quality on Emotion Dimensions

Predictor	**Outcome**	***p-value***	**CI Difference**		
	Statistically Significant Findings			***Non-Statistically Significant Findings***	
Sleep Quality (+)	Evening-to-morning change in valence	$p < .001$	0.27	Sleep Quality	Evening-to-morning change in arousal
Sleep Quality (-)	Morning-to-evening change in valence	$p < .001$	0.26	Sleep Quality	Morning-to-evening change in arousal
Sleep Quality (+)	Next Morning Valence	$p < .001$	0.23		
Sleep Quality (-)	Next Morning Arousal	$p = .001$	0.24		
Sleep Quality (+)	Subsequent Night Valence	$p = .001$	0.26	Sleep Quality	Subsequent Night Arousal

Note. Sign of (+) indicates positive association and sign of (-) indicates negative association. CI Difference = the absolute value of the confidence interval margin; a smaller absolute value score indicates greater statistical significance.

Figures

Figures A-B: Timing of Core Emotional Interactions Predicting SOL

Figure A: During the pre-sleep period**,** valence and arousal exhibited statistically significant interplay to predict the same night's SOL.

Figure B: Across the day into the night, there was a statistically significant interactive impact of valence on that night's SOL.

Figures C-D-E: Insomnia severity moderating impacts of Emotion on SOL

Figure C: Effect of evening-to-morning arousal on SOL vary as a function of insomnia severity.

Figure D: Effect of evening arousal on SOL vary as a function of insomnia severity.

Figure E: Effect of morning valence on SOL vary as a function of insomnia severity.

Figures F-G-H: Insomnia severity moderating impacts of Sleep Quality on Emotion

Figure F: Insomnia severity interacted with sleep quality to predict morning arousal.

Figure G: Insomnia severity interacted with sleep quality to predict evening-to-morning arousal.

Figure H: Insomnia severity interacted with sleep quality to predict morning-to-evening arousal.

Figures I-J: Insomnia Severity moderating impacts of Emotion on Sleep Quality

Figure I: Insomnia severity interacted with morning arousal to predict sleep quality.

Figure J: Insomnia severity interacted with evening valence to predict sleep quality.

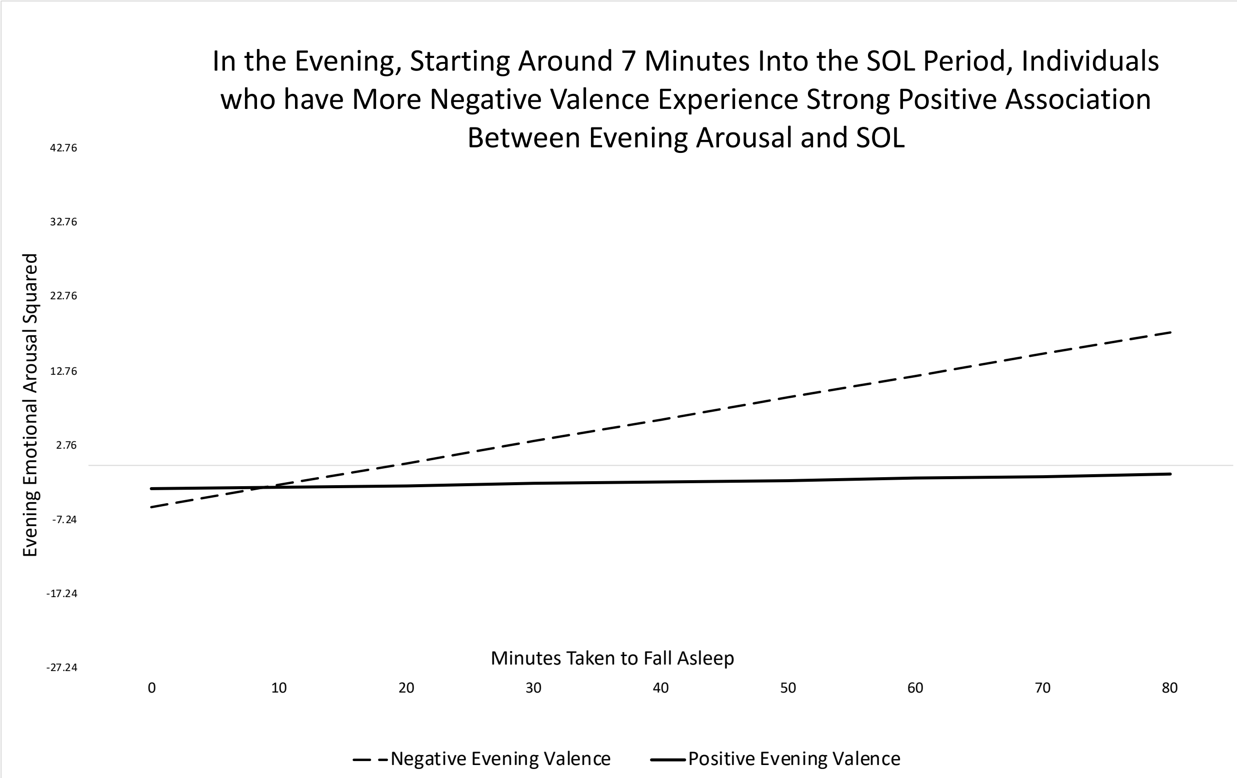

Figure A. Our graph reveals a significant interaction. People with more negative evening valence tended to exhibit a positive association between evening arousal and SOL. Starting early in the SOL period, people with more negative emotion tended to experience evening arousal and SOL as strongly related. People with more positive emotion did not experience such close connection between evening arousal and SOL. This graph shows that early in the pre-sleep period, the impacts of arousal on sleep vary as a function of negative versus positive valence.

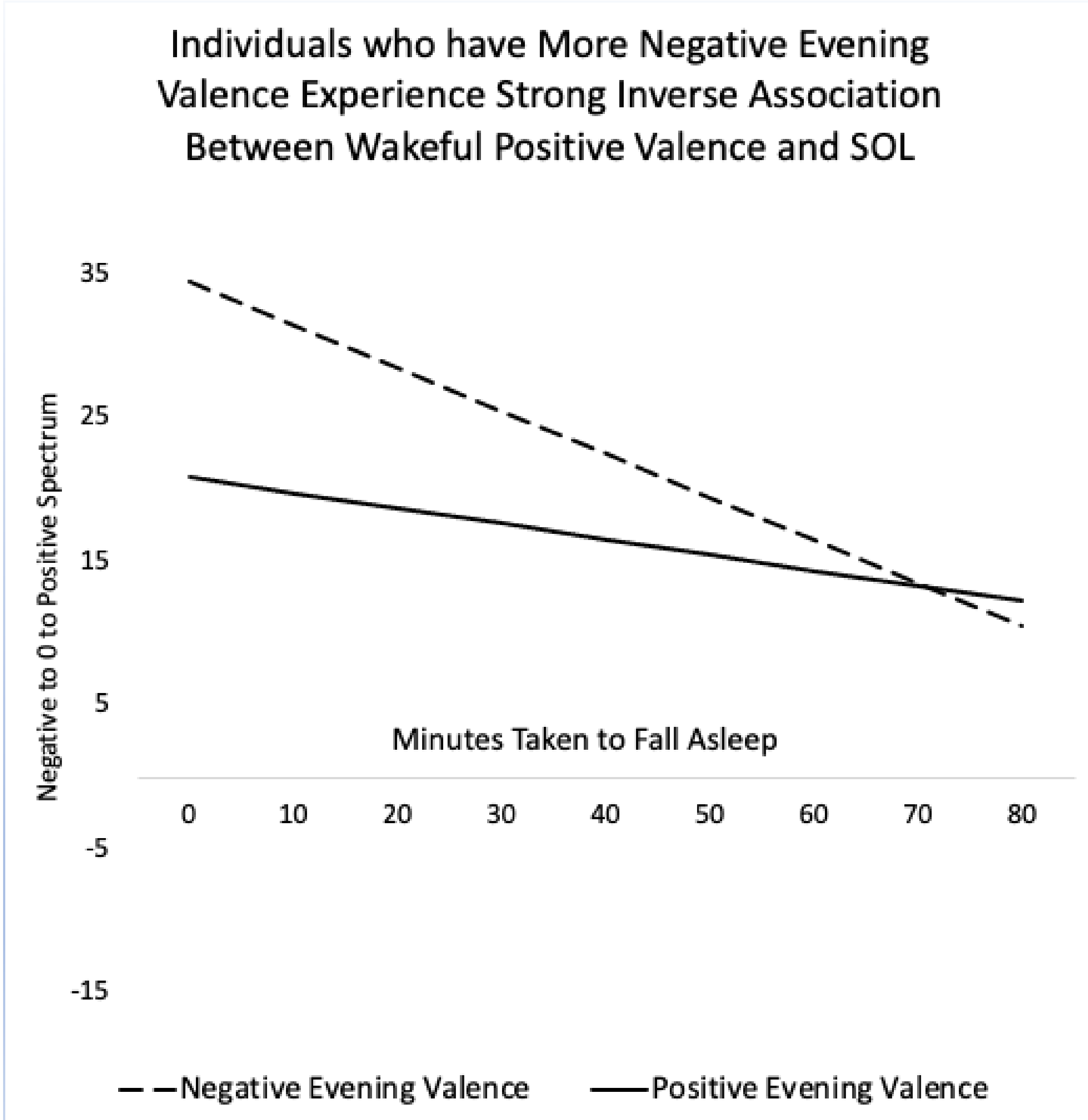

Figure B. Our graph reveals a significant interaction. People with more negative evening valence tended to exhibit an inverse association between positive morning valence and SOL. After about an hour into the sleep onset period, people with more negative emotion tended to experience that day's valence and SOL as strongly related. People with more positive emotion in the evening did not experience such close connection between that day's valence and SOL. This graph shows that with a prolonged pre-sleep period, the impacts of evening valence on SOL vary as a function of degree of negative versus positive valence that day.

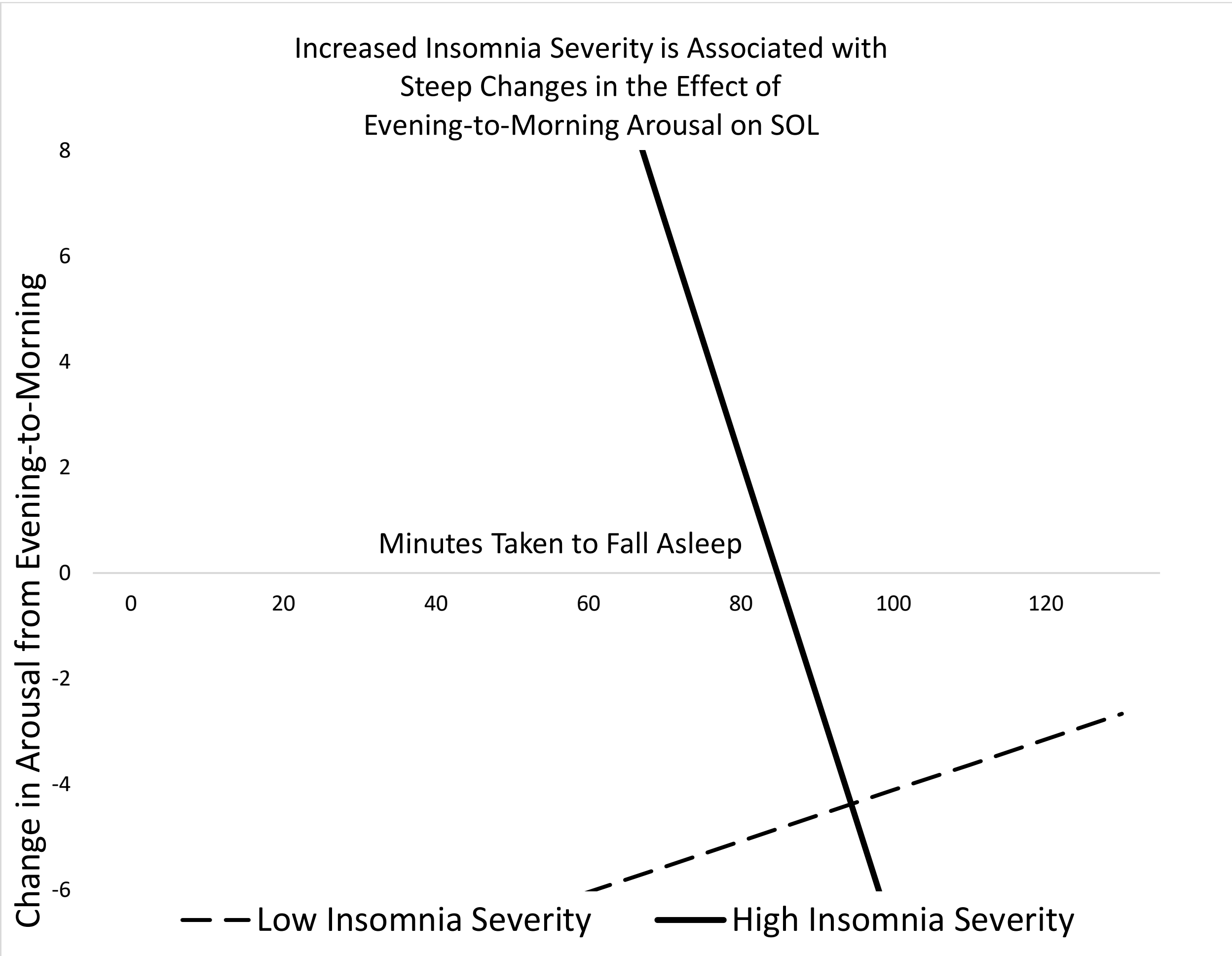

Figure C. Our graph reveals a significant interaction. People at high levels of insomnia tended to exhibit a negative association between evening-to-morning arousal and SOL. As SOL extended beyond 60 minutes, people with high levels of insomnia tended to experienced steeper decreases in arousal overnight. However, people at low levels of insomnia tended to exhibit a positive association between evening-to-morning arousal and SOL. As SOL extended beyond 60 minutes, people with low levels of insomnia experience less steepness in their decreases in arousal overnight. This graph shows that later in the pre-sleep period, the impacts of evening-to-morning arousal on sleep vary as a function of insomnia severity.

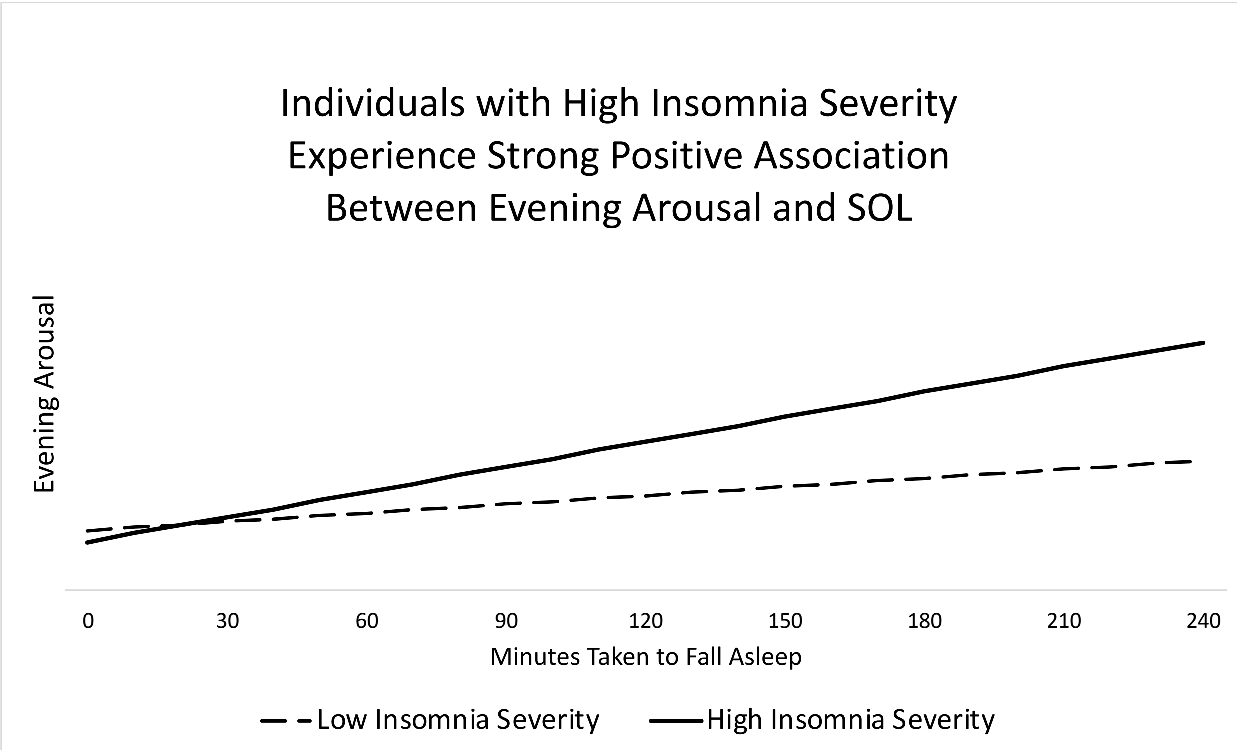

Figure D. Our graph reveals a significant interaction. People with low insomnia severity tended to exhibit a positive association between evening emotional arousal and SOL. Starting early in the SOL period, people with high insomnia severity experienced evening emotional arousal and SOL as strongly related, whereas evening emotional arousal and SOL were less strongly related for people with low insomnia severity. People with more positive emotion did not experience such close connection between evening arousal and SOL. This graph shows that early in the pre-sleep period, the impacts of evening emotional arousal on sleep vary as a function of insomnia severity.

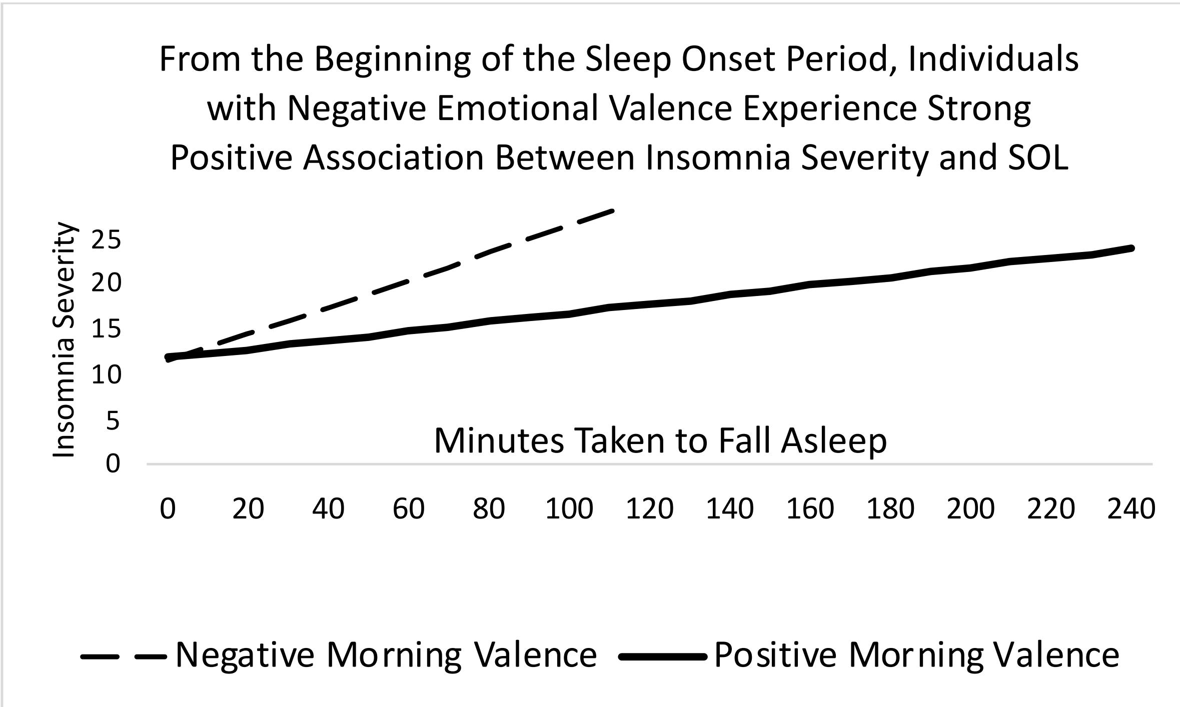

Figure E. Our graph reveals a significant interaction. People with more negative morning valence tended to exhibit a positive association between insomnia severity and SOL. Starting early in the SOL period, people with more negative emotion tended to experience close interrelationship between insomnia severity and SOL. People with more positive emotion did not experience such close connection between insomnia severity and SOL. This graph shows that early in the sleep onset period, the effect of wakeful positive valence on SOL varies as a function of insomnia.

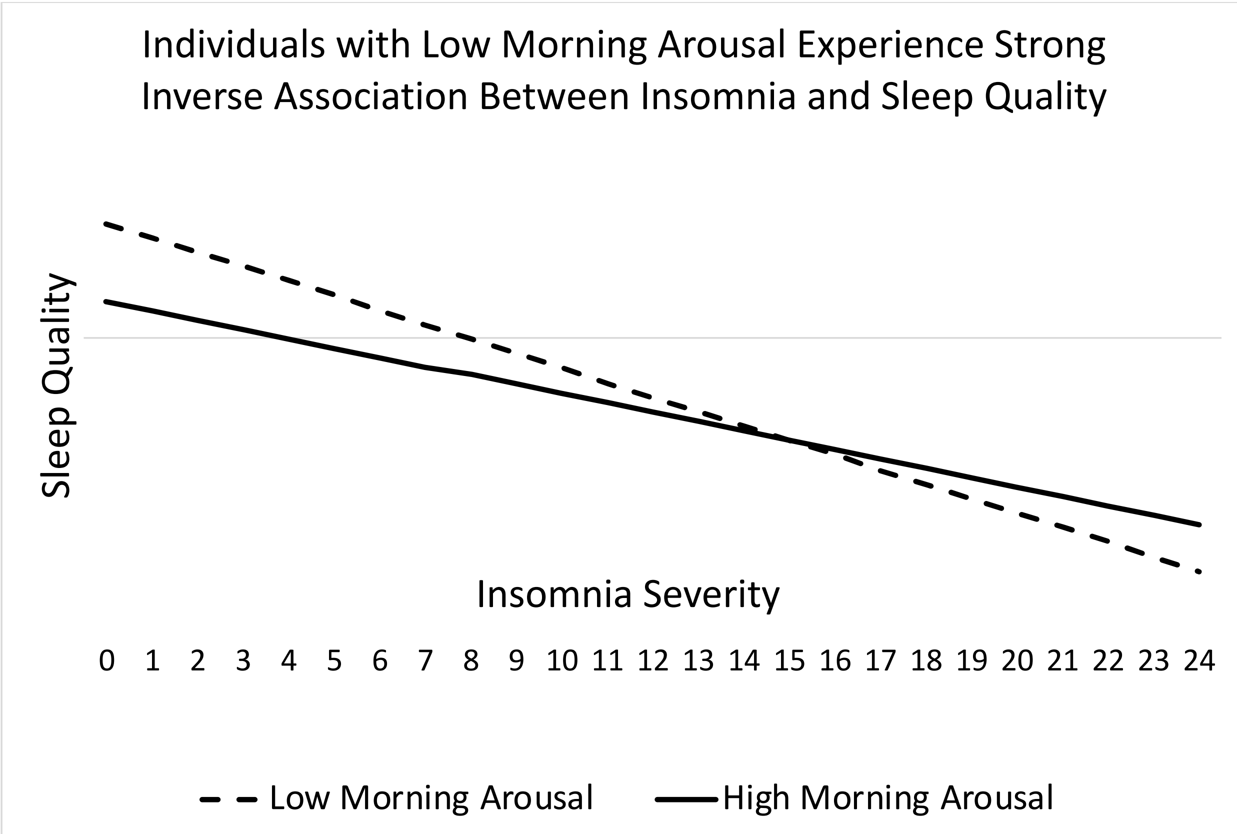

Figure F. Our graph reveals a significant interaction. People with low morning arousal experienced strong inverse association between insomnia severity and sleep quality. People with high morning arousal also exhibited an inverse association between insomnia severity and sleep quality. At clinically severity levels of insomnia—around a score of 15—the interaction effect occurred, prompting a steeper inverse slope for people with low morning arousal compared to people with high morning arousal. People with greater insomnia severity experience low morning arousal even after a night of good sleep. This graph shows that the impact of morning arousal on sleep quality varies as a function of insomnia severity.

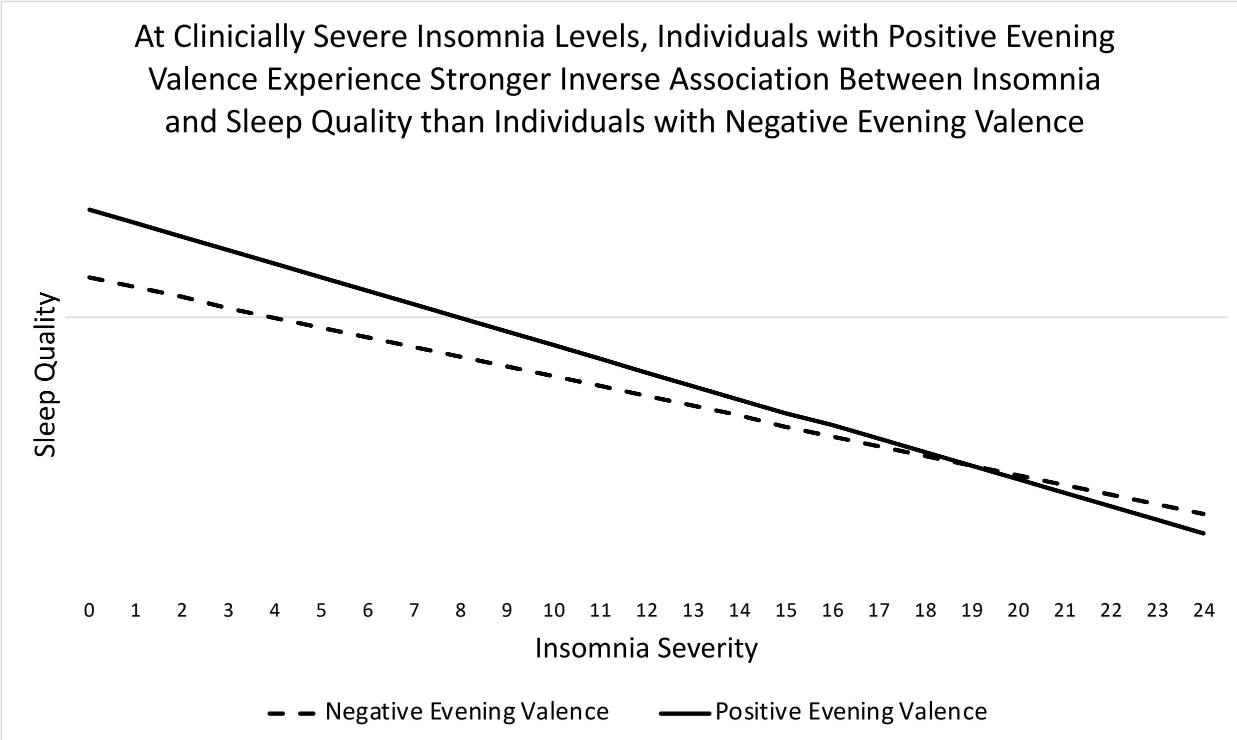

Figure G. Our graph reveals a significant interaction. People with positive evening valence and people with negative evening valence experienced strong inverse association between sleep quality and insomnia severity. At clinically severe levels of insomnia—around a score of 22—the interaction effect occurred, prompting a steeper inverse slope for people with positive evening valence compared to people with negative evening valence. People with higher insomnia scores experience positive valence as disruptive to sleep quality. This graph shows that the impact of evening valence on sleep quality varies as a function of insomnia severity.

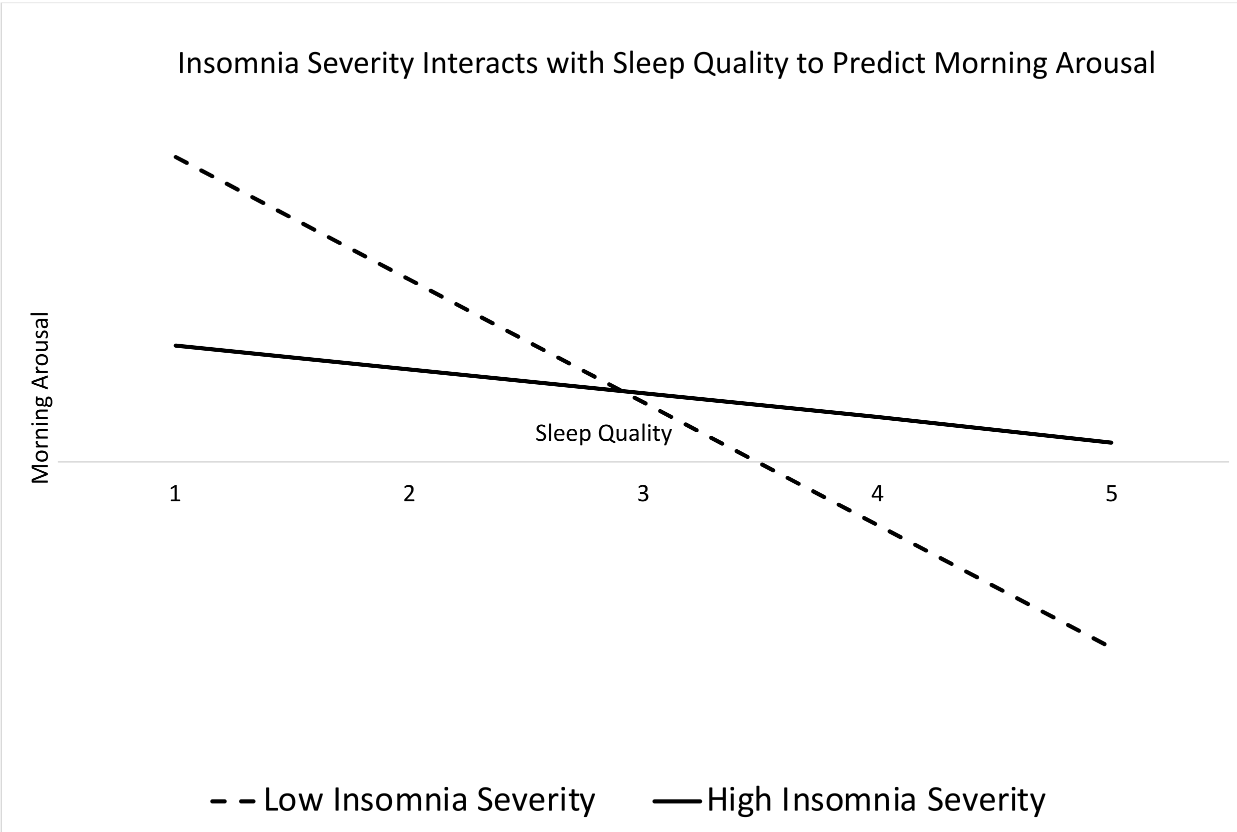

Figure H. Our graph reveals a significant interaction. People with low insomnia severity had strong inverse association between sleep quality and morning arousal. People with high insomnia severity had lower strength of association—though still statistically significant—between sleep quality and morning arousal. Morning emotional arousal is lower for individuals who have better sleep quality with lesser severity of insomnia. Additionally, morning emotional arousal is higher for individuals who have poorer sleep quality yet have lesser severity of insomnia. This graph shows that poor sleep quality and good sleep quality are differentiated by their associations between morning arousal and insomnia severity.

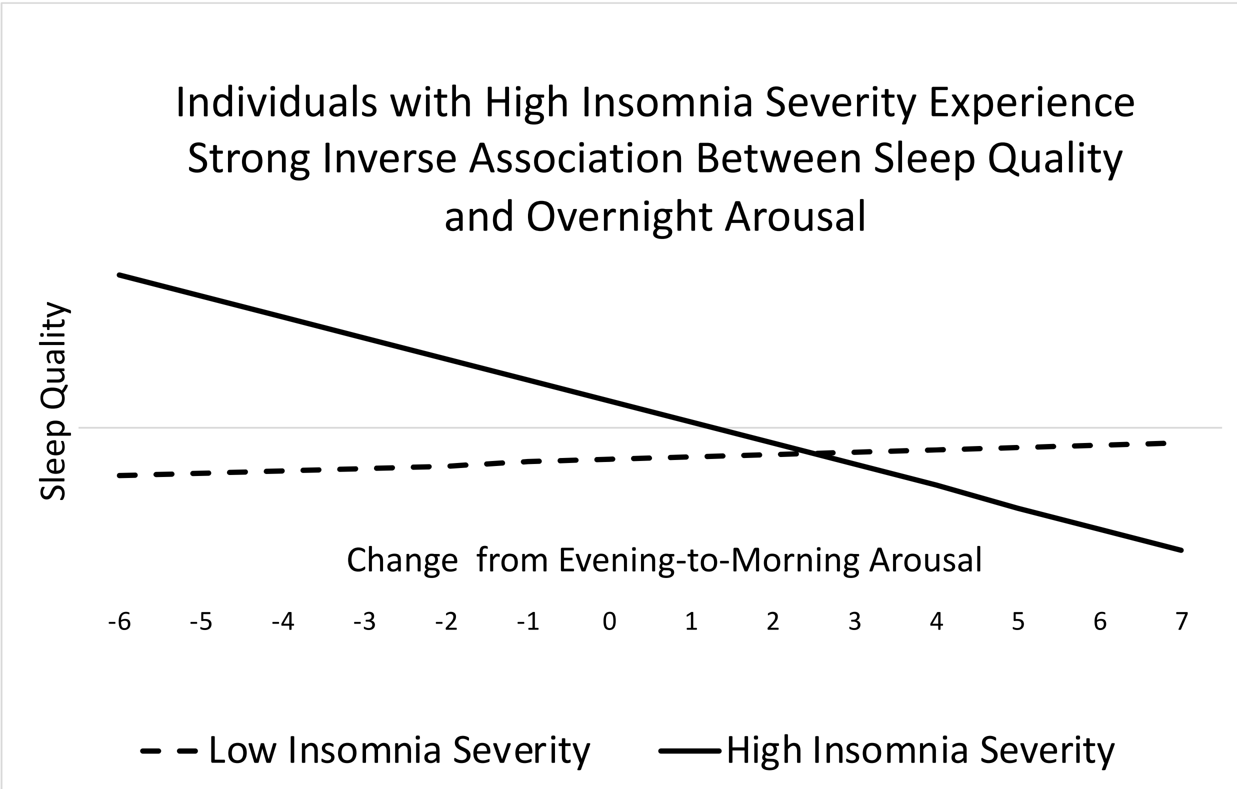

Figure I. Our graph reveals a significant interaction. People at high levels of insomnia tended to exhibit a strong inverse association between evening-to-morning arousal and sleep quality. People who experienced increases in emotional arousal from evening to morning experienced worse sleep quality if they had high insomnia severity. People who experienced decreases in emotional arousal from evening to morning experienced between sleep quality if they had high insomnia severity. An inverse association between sleep quality and evening-to-morning change in arousal existed only for individuals with high insomnia severity. Individuals with low insomnia severity did not exhibit statistically significant association between evening-to-morning arousal and sleep quality. This graph shows that the impacts of sleep quality on trajectories of evening-to-morning arousal vary as a function of one’s level of insomnia severity.

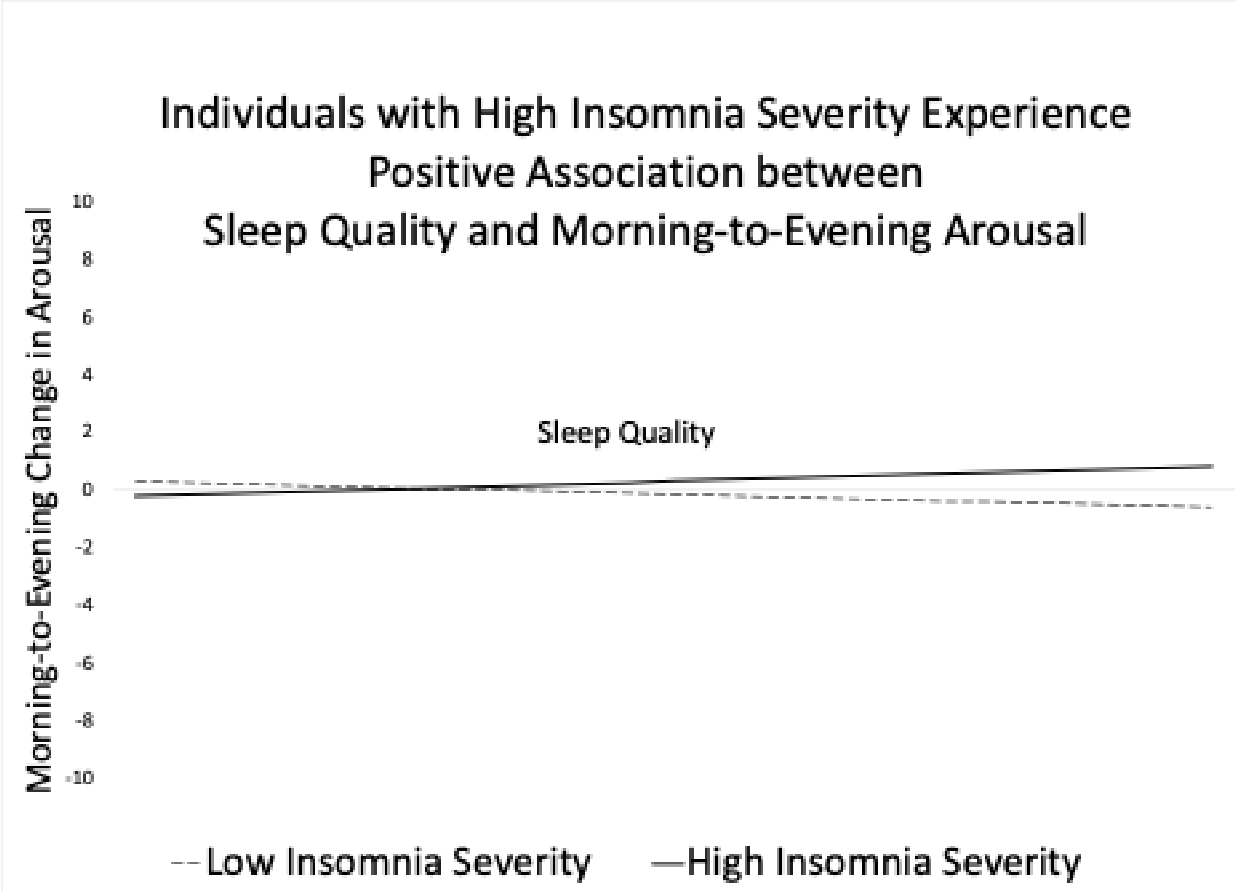

Figure J: Our graph reveals a significant interaction. People with high levels of insomnia tended to exhibit a strong positive association between morning-to-evening arousal and sleep quality. All participants tended to exhibit plateau in arousal from morning-to-evening or slight increases in arousal from morning-to-evening. People with low insomnia severity exhibited plateaus in morning-to-evening arousal. People with high insomnia severity exhibited slight increases in morning-to-evening arousal. This graph shows that the impacts of sleep quality on trajectories of morning-to-evening arousal vary as a function of one's level of insomnia severity.

Appendix A1: Informed Consent Document

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Cyclical Change in the Sleep-Emotion Relationship

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Study Description and Purpose

Good and poor sleep have many influences and are affected by waking experiences. Researchers have discovered some but not all of these relationships. This research study will examine relationships between sleep and emotion characteristics.

Information Provided by Participants

By participating in this study, you will be providing personal information (for example, ethnicity, gender, education, medications, etc.), and information about your sleep and emotions. Some of the information you provide will be sensitive (for example, medications you are taking); however, none of the information you provide is personally identifying and therefore cannot be used to determine your identity.

Data Confidentiality

ALL INFORMATION YOU PROVIDE WILL BE ANONYMOUS! Security and privacy are of paramount importance. MTurk uses industry standard encryption and security best-practices to keep the data we collect safe and confidential. All interactions through the MTurk website are secured to ensure that your credentials and responses are secure. Your choice of username is the only thing identifying you in the system with your responses to questions. Your responses are not linked to any form of personal identifying information such as your name, phone number, or email address unless you have included that information in your account username. The information you provide could be used as part of a poster or oral presentation at a conference, or as part of a journal or book publication. In this case, researchers would combine your information with information from other participants to create statistics that do not identify specific participants (for example, mathematical averages).

Participation Description

Participation begins with your agreement (in other words, consent) to participate. If you consent to participate, you will begin the study by completing several online questionnaires through MTurk. Starting the day after you complete these questionnaires, you will log into your MTurk account to complete surveys twice per day (once in morning, once in evening) for 20 days.

Total time required for study

Initial Online Questionnaires: 30-45 minutes

Daily Questionnaires: 5-10 minutes per day for 20 days
Anticipated Total Participation Time: 1 hour and 45 minutes – 4 hours

Potential Risks and Benefits to Participants
Some participants may find discussing or answering questions about sensitive topics stressful. This is normal. The level of stress that some people experience, however, is not outside the range of everyday stress. It is also possible that tracking your sleep experience may lead you to feel concerned about your own sleep quality. If you become uncomfortable with the task, you can end the study immediately without penalty by contacting an investigator and/or by no longer filling out survey questions. If you have concerns about your own sleep habits, please contact your health provider.

There are also potential benefits to participants. Some participants report that completing questionnaires has given them better insight into their sleep and emotion patterns. The information you provide will also help scientists understand relationships between variables that can be used to improve treatment for people with sleep problems.

Compensation
All compensation will be dispensed via MTurk. They currently use a standardized point system that allows users to earn Amazon gift cards or money to donate to preferred charities in exchange for the time you spend completing surveys. The funds are delivered electronically through your MTurk account to maintain your privacy. For more information on compensation, please refer to the help section of your MTurk account.

Participation is VOLUNTARY
Participation in this study is *ENTIRELY VOLUNTARY*. You may decline to participate in this study *at any point during the study*. You may also choose to have your information destroyed or deleted at any point during the study by contacting the Principal Investigator or Co-Investigator and stating that you would like your data removed from the study or destroyed. Anyone who decides to terminate their participation in the study will still receive credit for the time that they participated, according to the guidelines set forth by MTurk

Contacts for Questions and Concerns

If you have questions or concerns about your participation in this study, you may contact the Principal Investigator or Co-Investigator at the contact information provided above. For technical support related to the use of the MTurk platform, please contact the support team using the following link: https://www.mturk.com/worker/help

If you have any concerns or complaints about your treatment as a research participant, please contact the Suffolk University Institutional Review Board at 1-888-634-4378 or irb@suffolk.

Appendix A2: Demographics Questionnaire

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1. *What is your self-identified gender?*
Male Female Non-binary
Transgender male Transgender female Other/Prefer Not to Say

2. *What is your age, in years?* ______

3. *What is your race (check all that apply)?*
Caucasian/White African American/Black Hispanic/Latino
Asian Native American Other:________________

4. *What is your religious affiliation(s), if any?* ____________________________________

5. *Do you consider yourself spiritual?*
Yes No Other:_______________________

6. *Do you expect to work overnight shifts within the next 22 days?*
Yes No Other:_______________________

7. *What is the highest level of education that you have completed?*
Primary/Elementary School (will include a branch to indicate grade level completion)
Middle School (will include a branch to indicate grade level completion)
High School (will include a branch to indicate grade level completion)
Associate's Degree
Bachelor's Degree
Graduate Degree
Note: If the participant did not complete high school the study will end because the participant may not have reading level necessary for participation.

8. *Have you ever been diagnosed with narcolepsy or REM sleep behavior disorder?*
Yes No (If yes, will include a branch to indicate current sleep disorder status)

9. *Have you ever been diagnosed with insomnia disorder?*
Yes No

10. *Do you take barbiturates, either for medical or recreational use, or have you done so in the last month? Examples of barbiturates include phenobarbital, amobarbital (Amytal), pentobarbital (Nembutal), secobarbital (Seconal), butabarbital (Butisol), and mephobarbital (Mebaral*)
Yes No

11. *Are you currently taking any of the following MAOIs (monoamine oxidase inhibitors), or have you done so in the last month? Examples of MAOIs include phenelzine (Nardil, Nardelzine), tranylcypromine, or isocarboxazid (Marplan, Enerzer)?*
Yes No

12. *Are you currently taking any of the following medications or regularly use any of the following substances (circle all that apply)?*
Benzodiazepines (e.g., Klonopin, Ativan, Valium, Xanax)
Benzodiazepine-receptor agonists (e.g., Ambien, Lunesta, Sonata)
Selective serotonin reuptake inhibitors (SSRIs; e.g., Celexa, Lexapro, Prozac, Paxil, Zoloft)
Amphetamines (e.g., Adderall, Ritalin, Concerta, methamphetamine, MDMA/Ecstasy)
Opiates (e.g., Percocet, Oxycontin, Vicodin, heroin, methadone, codeine)
Tobacco/Nicotine (e.g., cigarettes, cigars, chewing tobacco, “dip,” nicotine gum or patch)
Melatonin
Other:_______________

13. *Did you start or stop taking medications in the last month? If so, which ones (circle all that apply)?*
Yes No
Benzodiazepines (e.g., Klonopin, Ativan, Valium, Xanax)
Benzodiazepine-receptor agonists (e.g., Ambien, Lunesta, Sonata)
Selective serotonin reuptake inhibitors (SSRIs; e.g., Celexa, Lexapro, Prozac, Paxil, Zoloft)
Amphetamines (e.g., Adderall, Ritalin, Concerta, methamphetamine, MDMA/Ecstasy)
Opiates (e.g., Percocet, Oxycontin, Vicodin, heroin, methadone, codeine)
Tobacco/Nicotine (e.g., cigarettes, cigars, chewing tobacco, “dip,” nicotine gum or patch)
Melatonin
Other
(If participant answers “Yes”) *Starting or stopping these substances can affect your sleep for several weeks. We ask that you please delay beginning this study until your medication use has been stable for a period of one month. At that time, please start the study again.*

14. *How often do you typically have any kind of drink containing alcohol?*
Every day
Most days of the week
Once or twice a week
Two or three times a month
Once per month or less

15. *When you drink alcohol, how many drinks do you have in a typical 24-hour day?*
More than 10
Between 5 and 10
Between 2 and 4
1 drink or less

16. *How often do you typically have caffeine (coffee, tea, energy drink, etc.)?*
Every day
Most days of the week
Once or twice a week
Two or three times a month
Once per month or less

17. *When you drink caffeine, how many drinks do you have in a typical 24-hour day?*
More than 10
Between 5 and 10
Between 2 and 4
1 drink or less

18. *What is the latest time that you usually consume caffeine each day?*
12 am to 12 am scale

19. *Do you usually sleep with a bed partner?*
Yes No Other:____________________

20. *Do you meditate regularly?*
Yes No

21. *In the last month, approximately how many bad dreams have you had? A bad dream is a dream with distressing content that did NOT cause you to wake up during the dream event.*
Not during the past month
Less than once a week
Once or twice a week
Three or more times a week

22. *In the last month, approximately how many nightmares have you had? A nightmare is a dream with intense, vivid distressing content that caused you to wake up during the dream event.*
Not during the past month
Less than once a week
Once or twice a week
Three or more times a week

Appendix A3: Insomnia Severity Index (ISI)

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Insomnia Severity Index

The Insomnia Severity Index has seven questions. The seven answers are added up to get a total score. When you have your total score, look at the 'Guidelines for Scoring/Interpretation' below to see where your sleep difficulty fits.

For each question, please CIRCLE the number that best describes your answer.

Please rate the CURRENT (i.e. LAST 2 WEEKS) SEVERITY of your insomnia problem(s).

Insomnia Problem	None	Mild	Moderate	Severe	Very Severe
1. Difficulty falling asleep	0	1	2	3	4
2. Difficulty staying asleep	0	1	2	3	4
3. Problems waking up too early	0	1	2	3	4

4. How SATISFIED/DISSATISFIED are you with your CURRENT sleep pattern?

Very Satisfied	Satisfied	Moderately Satisfied	Dissatisfied	Very Dissatisfied
0	1	2	3	4

5. How NOTICEABLE to others do you think your sleep problem is in terms of impairing the quality of your life?

Not at all Noticeable	A Little	Somewhat	Much	Very Much Noticeable
0	1	2	3	4

6. How WORRIED/DISTRESSED are you about your current sleep problem?

Not at all Worried	A Little	Somewhat	Much	Very Much Worried
0	1	2	3	4

7. To what extent do you consider your sleep problem to INTERFERE with your daily functioning (e.g. daytime fatigue, mood, ability to function at work/daily chores, concentration, memory, mood, etc.) CURRENTLY?

Not at all Interfering	A Little	Somewhat	Much	Very Much Interfering
0	1	2	3	4

Guidelines for Scoring/Interpretation:

Add the scores for all seven items (questions 1 + 2 + 3 + 4 + 5 +6 + 7) = _______ your total score

Total score categories:
0–7 = No clinically significant insomnia
8–14 = Subthreshold insomnia
15–21 = Clinical insomnia (moderate severity)
22–28 = Clinical insomnia (severe)

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Appendix A4: Consensus Sleep Diary

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Sample **Consensus Sleep Diary-Core** ID/Name:____________________

Today's date	4/5/11							
1. What time did you get into bed?	10:15 p.m							
2. What time did you try to go to sleep?	11:30 p.m							
3. How long did it take you to fall asleep?	55 min.							
4. How many times did you wake up, not counting your final awakening?	3 times							
5. In total, how long did these awakenings last?	1 hour 10 min.							
6. What time was your final awakening?	6:35 a.m.							
7. What time did you get out of bed for the day?	7:20 a.m							
8. How would you rate the quality of your sleep?	☐ Very poor ☑ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good	☐ Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good
9. Comments (if applicable)	I have a cold							

Appendix A5: Self-Assessment Manikin (SAM)

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Instructions:

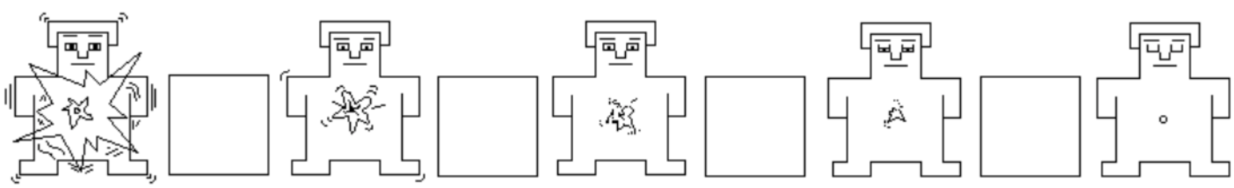
In this study we are interested in how people represent their emotional experiences. Below you will see 2 sets of five figures, each arranged along a 9-point continuum. We call this set of figures SAM, which stands for self-assessment manikin. You will be using these figures to rate how you feel while completing this measure. SAM shows two different kinds of feelings: Pleasant vs. Unpleasant and Activated vs. Calm.

Please use the mouse to click and indicate your ratings.

--

Arousal rating:

The activated vs. calm dimension is a type of feeling that SAM can represent. Below is the activated-calm scale. At one end of this scale are feelings associated with being extremely stimulated, excited, frenzied, jittery, wide-awake, aroused. At the other end of the scale are feelings associated with being relaxed, calm, sluggish, dull, unaroused. The activated-calm dimension is completely independent of the pleasantness of the feeling. That is, feelings can be equally activating whether they are pleasant or unpleasant. This scale allows you to describe intermediate feelings of arousal. Use the entire 9-point range when making your ratings. To represent your emotional arousal experience you can click on the boxes between the SAM figures or click on the SAM figures themselves.



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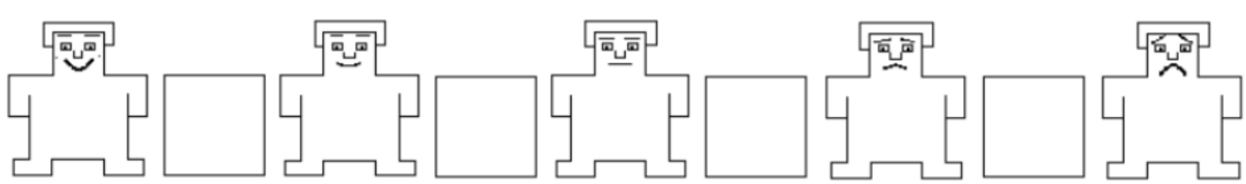
Valence rating:

The pleasant-unpleasant dimension is another type of feeling that SAM can represent. Below is the pleasant-unpleasant scale, which ranges from a smile to a frown. At one end of this scale are representations of feeling extremely pleasant, happy, satisfied, content, hopeful, positive. At the other end of the scale are representations of feeling completely unpleasant, unhappy, annoyed, unsatisfied, melancholic, despaired, bored, negative. This scale allows you to describe intermediate feelings of pleasantness. Use the entire 9-point range when making your ratings. To represent your emotional valence experience you can click on the boxes between the SAM figures or click on the SAM figures themselves.



Appendix B: Order Effects

Within research and clinical sectors, uncertainty remains regarding the influence of response biases due to order of survey presentation in self-reporting of sleep and emotion. Within cognitive theory it is well established that order effects impact self-reporting behavior depending on survey administration order (Krosnick & Alwin, 1987), but specific order effects from assessing sleep and emotion components have not been clarified. To date, the current author was unable to find published any studies addressing this methodological question.

Examining order effects predicting sleep-emotion cyclicity: Given the subjectivity of self-appraisal, it is anticipated that associations among emotion variables (arousal and valence) and sleep variables (SOL and sleep quality) may be impacted by the order in which the constructs are assessed, demonstrating effect of measurement order on patterns of self-report.

Testing How Order Effects Predicts Sleep-Emotion Patterns. An independent samples t-test was conducted to examine group differences depending on whether the mental frame was set as sleep-emotion or emotion-sleep. We rejected the null of Levene's test and concluded that the variance in certain emotion parameters of the Order 1 sample was significantly different than that of the Order 2 sample ($p < .001$). Here we see that we should look at the "Equal variances not assumed" row. Since the p-values for Morning Valence and Evening Arousal are less than our chosen confidence interval of 0.05, we can reject the null hypothesis, and conclude that the mean Morning Valence and Evening Arousal ratings for Order 1 sample and Order 2 sample are significantly different. People in Order 1 (Emotion-Sleep) have significantly lower ratings of Evening Arousal ($M = 3.30$, $SD = 1.74$) compared to people in Order 2 (Sleep-Emotion) who had comparatively higher ratings of Evening Arousal ($M = 3.94$, $SD = 1.98$). This suggests that morning order or frame in reporting about sleep and emotion questions impacts one's ratings of

arousal in the evening. Additionally, morning order or frame seems to impact ratings of valence in the morning. People in Order 1 (Emotion-Sleep) report significantly less positive valence (M = 5.77, SD = 1.62) compared to people in Order 2 (Sleep-Emotion) who rated themselves as having more positive valence (M = 6.06, SD = 1.89).

Order effects were then tested through multilevel lagged regressed change analysis. Two statistically significant impacts emerged and were related to each other. Sleep quality predicted subsequent change in morning-to-evening arousal (Estimate = -.50, SE = .17, df = 94.97, t = -2.97, p = .004, CI = -.83 to -.16). For individuals who answered emotion items then sleep items (Order 1), better sleep quality predicted decreases in arousal from post-sleep to pre-sleep. In comparison, for individuals who answered sleep items then emotion items (Order 2), better sleep quality predicted increases in arousal from post-sleep to pre-sleep. This indicates that the morning frame through which participants were prompted to orient to their internal experience had lasting impacts on participants' emotional arousal.

Self-reporting about sleep quality first (Order 2) impacted one's perception of their subsequent arousal trajectory across the day, into the evening. Sleep quality also predicted subsequent evening arousal (Estimate = -.54, SE = .24, df = 137.22, t = -2.22, p = .028, CI = -1.02 to -.06) and did not predict morning arousal. In Order 1, better sleep quality predicted decreases in evening emotional arousal, compared to Order 2 which predicted increases in evening emotional arousal, impacted by sleep quality. This predictive effect of sleep quality emerged above and beyond the main effects of insomnia severity on evening arousal. These results reveal highlight that the order of self-report primarily impacts the emotional arousal dimension of experience. The emotional valence dimension of experience was unaffected by order of self-reporting behavior, further suggesting greater stability of valence than arousal.

These findings demonstrate how differential time of circumplex interplay is experienced depending on the frame or mental set one that is accustomed to adopting each morning. In the morning, extra strength of interrelatedness between emotional and sleep occurs more for people who wake up and reflect on their emotion first. This primacy of emotional arousal (Order 1) is seen as relating to both bookends of the sleep experience: SOL and sleep quality.

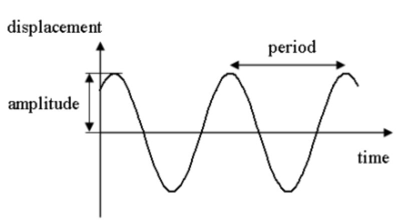
Caution should be taken when interpreting the above findings about order effects. The meaning of order effects as related to sleep-emotion interaction is unknown. It is a real perceived effect, but it may speak more to memory biases, such as a recency effect moreso than a specific framing effect. This is another fruitful area of research to advance methodological knowledge.

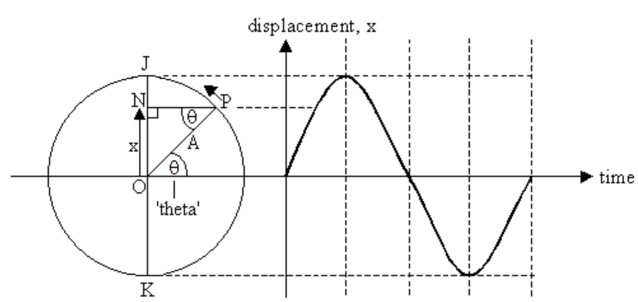
Appendix C: Spherical Representation of Sleep-Emotion Relationships

Our study suggests possibility for detection of healthy spherical representation of self-change over time, a symbol of psychological well-being. Consider the constant pi (π) = 3.1415, the circumference of a circle = $2(\pi)r$, and the volume of a sphere where volume = $4/3(\pi)r^3$ where r equals radius. The radius units of measurement can be calculated by plotting one's circumplex pattern and seeing how far away from healthy self-regulation one's scores exist.

Assessing change over time, an individual's sleep-emotional circumplex fluctuation patterns could be mapped. Wakefulness emotion research (Kuppens et al., 2011) has not been successful in detecting the mechanisms that underlie emotional inertia to date, but spherical models of consciousness have been proposed (Pintimalli et al., 2020; Paoletti & Soussan, 2019). Our model both reflects fullness and parsimony of subjectivity across forms of consciousness.

Current EMA study findings offer a framework for individualized psychological assessment and intervention plans. A circumplex sleep aid could assist in tracking progress toward achieving more advantageous or desirable pattern of self-perception. Deviation from one's emotional set-point could be addressed and monitored as an aid toward establishing emotional equilibrium. These images were taken from google.com to illustrate the arithmetic:





Appendix D: Extended Literature Review

This Extended Literature Review is organized into six sections that, together, describe the state of sleep-emotion literature and propose an updated conceptualization of sleep-emotion relation. It posits that methodologically and analytically sophisticated investigations of arousal and valence patterns in relation to sleep are instrumental for understanding functional and dysfunctional human processes. The first section describes research about sleep-wake regulation, noting how biological principles and processes can guide studies on emotional principles and processes (1). Next, the paper distills evidence that emotional arousal and emotional valence are centrally involved in sleep and sleep disruption (2). The third section provides rationale for the decision to study sleep onset latency and sleep quality as the two primary sleep variables (3). The fourth section describes how the study of insomnia and healthy emotion-sleep trajectories can advance etiological understanding of primary and secondary insomnia disorders with other psychiatric profiles (4). The fifth section emphasizes procedural and analytic techniques amenable to adequate depiction of internal human change processes (5). Sixth, the author proposes a novel and empirically grounded sleep-emotion cycle as an important conceptual model for understanding continuity in human experience (6).

Sleep-Wake Regulation (1)

Evidence from the study of biological sleep-wake transition offers clues about what to expect from the behavioral study of emotionally based transition. Within the field, there is a call for a focus on mechanistic science, requesting that scientists orient their conceptualization of interrelated variables toward identifying psychological operations that align with biological structures (Thomas & Sharp, 2019; National Institute of Mental Health, 2008). Within the study of insomnia development (Harvey, 2002; Morin, 1993), biological oscillation patterns of sleep-

wake transition are too reductionistic to capture the nature of this psychologically based sleep disruption. However, healthy biological sleep-wake oscillation patterns are well-established (Piantoni et al., 2013; Salentin, van der Helm, & Walker, 2014) and provide a template for assessing how healthy and unhealthy emotional patterns can be mapped.

Biological oscillation patterns inform the current study design. A full description of biological propensity in the sleep-wake cycle is beyond the scope of the current behavioral investigation, but some key facts are essential to recognize (see Blumberg, Gall, & Todd, 2014). The biological circadian cycle reflects continuous oscillation across a period of approximately 24 hours (Blumberg et al., 2014). Across these periods, lightness and darkness each cue functional neurochemical adjustments necessary for waking and sleeping, respectively (Dunlap, Loros, & DeCoursey, 2004). Waking is associated with cortisol increase and melatonin decrease whereas sleeping is associated with cortisol decrease and melatonin increase (Backhaus, Junghanns, & Hohagen, 2004; Dibner, Schibler, & Albrecht, 2010; Dijk & Lockley, 2002; Dunlap et al., 2004). Additionally, dopamine is depleted across the waking period and is replenished across the sleeping experience (Gottesman, 2002; Oishi & Lazarus, 2017; Rial, Canellas, Gamundi, Akaarir, & Nicolau, 2018). Morning To translate, this implies that healthy functioning would involve activation in the morning and de-activation in the evening. Indeed, this functional chronotype pattern has been highlighted in psychiatric research (Hasler, Insana, James, & Germain, 2013; Lemoine, Zawieja, & Ohayon, 2013). Considering how the complex orchestration of the circadian propensity exists at the molecular level (e.g., Prasai, Pernicova, Grant, & Scott, 2011; Relogio et al., 2011; Reppert & Weaver, 2002), psychological scientists need to confirm whether people’s reflections (i.e., behavioral reporting patterns) match. It is expected that certain emotional patterns would synergistically encourage day-to-day well-being.

Behavioral and biological alignment. Circadian alignment is a term that describes congruence between one's behavior and one's natural biological rhythm (Dyche, Couturier, & Hall, 2015, p. 15). Circadian misalignment describes a common occurrence wherein individuals' behavior fluctuates in a way that contradicts their biological sleep-wake rhythm (Dyche et al., 2015, p. 15; Daut et al., 2019; Lund, Reider, Whiting, & Prichard, 2010). Circadian misalignment can by driven by many variables and stimuli dependent on time of day (e.g., drinking caffeine at night; Kerpershoek, Antypa, & Van den Berg, 2018). Research suggests links between circadian misalignment and the gamut of psychiatric manifestations of human suffering, including anxiety disorder (Lemoine et al., 2013), unipolar depressive disorder (Selvi et al., 2010; Hasler et al., 2010), bipolar disorder (Mansour et al., 2005; Soehner et al., 2005), posttraumatic stress disorder (Hasler et al., 2013; Short, Allan, & Schmidt, 2017), personality disorder (Lemoine et al., 2013), and addiction disorder (Lemoine et al., 2013; Logan et al., 2017). Most relevant to the present investigation, insomnia disorder and circadian misalignment seem to be reciprocally maintained (Lack, Lovato, & Micic, 2017). It is essential to consider how healthy people represent or model their own intersecting sleep-emotion psychology through (a) adaptive activation patterns (i.e., increased arousal in morning and decreased arousal in evening), (b) self-reinforcing pleasure involved in sleep-wake health (i.e., sleep-dependent increase in positive emotion rather than negative emotion), and (c) perceived sleep health (i.e., high sleep quality and efficiency of sleep initiation). The nature of reciprocal relation between sleep health and emotional health may be an important indicator of well-being (Kahn, Sheppes, & Sadeh, 2013; Pilcher & Huffcutt, 1996). An empirically supported cyclic model of sleep-emotion health may be reflected by time-specific behavioral patterns that align with circadian rhythmicity as indicated by morning-evening lightness-darkness timing.

Insomnia disorder is the primary disorder of interest in the current study in part because of the high comorbidity rates (approximately 50-80 percent) of insomnia features with other psychiatric disorders (Fairholme et al., 2013; Krystal, 2012; Smith et al., 2002). Additionally, investigations of its emotional constituents have never been published. Along a gradient of healthy to psychopathological sleep experience, differential relation between specific emotion and sleep variables may elucidate etiological trajectories of insomnia development. It may be the case that healthy sleepers' emotional representations are organized and operate in ways that complement biological propensity for sleep. It may also be the case that people with insomnia symptoms exhibit uncomplimentary emotional organization and operation patterns in the morning and/or evening (Buysse et al., 2007), reflecting behavioral misalignment in relation to biological sleep propensity.

Emotion Dimensions and Sleep (2)

Emotion is defined as a process that is triggered by internal and external stimulation characterized by a valence component, whereas affect is defined less dynamically but more categorically as conditions that contribute to good-bad discrimination (Baglioni et al., 2010). In research focused solely on waking experience, the distinction between emotion and affect is complicated and influenced by many factors that are not directly explored within the focused scope of the current study (see Russell & Barrett, 1999). For the purpose of understanding how people conceptualize their internal experience, the distinction is a matter of semantic preference. However, for the purpose of understanding how people conceptualize their internal experience in relation to *sleep*, a conceptual distinction is warranted. Affect has been identified and used to describe an internal construct that arises abruptly and changes across time (Russell and Barrett, 1999). The construct is considered an emotion when it becomes aimed toward something

(Russell and Barrett, 1999), such as sleeping. Measures of internal states need to account for the motivational component (i.e., the sleep drive) in subjective representation. Therefore, emotional experience is the more applicable construct in the current investigation.

A measure of circumplex emotional dimensions allows detection of change involved in sleeping and waking transitions (Bradley & Lang, 1994). The field's commonly used measure of affect (Watson & Clark, 1988; Watson & Clark, 1994) cannot detect this. To depict the nature of sleep-related transition (Sewitch, 1984), a measure that assesses change across spectra (Bradley & Lang, 1994; Lang, 1980) is more representative than a measure that disjoints constructs (Seib-Pfeifer, Pugnaghi, Beauducel, & Leue, 2017; Terraciano, McCrae, & Costa, 2003) and therefore can only assess discontinuity. A major issue in sleep-emotion research is that the focus on momentary assessment has detracted from the necessary appreciation for construct fluidity. Certainly, an emotional construct should be observable (i.e., reportable) at any moment. Yet the way that a participant completes a self-report measure about an internal construct is dependent on how that participant is prompted, by the researchers, to represent it. Participants cannot report about change in emotional constructs if given measures that cannot detect change across spectra. It may be the case that healthy individuals' emotions a perceived to modulate differently depending on sleeping and waking contexts; to date, cyclical fluctuation has not been tested.

The circumplex model purports that emotional phenomena can be represented as the combination of two dimensions: arousal and valence. *Arousal* refers to the felt activation (activated or deactivated). *Valence* refers to hedonic tone (pleasure or displeasure) of an emotional representation. The plotting of arousal and valence in combination organizes internal states around the circumference of a circle. It allows representation of internal experience along a negative-positive continuum of valence as well as an activated-calm continuum of arousal

(Bradley & Lang, 1994; Lang, 1980; Russell, 1980; Russell & Barrett, 1999). The distance between any two states around the circumference is a function of the similarity between the two states, with similar emotional states being situated near each other and dissimilar states far away from each other (the most dissimilar situated 180 degrees from each other; Remington, Fabrigar, & Visser, 2000). Thus, the similarity or dissimilarity between two emotional states is a function of the valence and arousal level comprising said states. There is increasing consensus among researchers that arousal and valence contribute to emotional experience (as cited in Barrett, 1998), but it is unclear how fluctuation across these two dimensions contributes to healthy sleep versus insomnia. The functional similarity of emotional states may relate to how people organize their internal experience (Barrett, Mesquita, Ochsner, & Gross, 2007) according to whether they are trying to gain an optimal sleep experience or an optimal waking experience.

It has become common for sleep investigations to represent emotion disjointedly across two separate scales—negative-neutral and positive-neutral—each characterized by high arousal and thus unidimensional orthogonal representation (Bouwmans, Bos, Hoenders, Oldehinkel, & Jonge, 2017; Gieselmann, Ophey, de John-Meyer, & Peitrowsky, 2012; Hasler et al., 2012). This critique is not to imply that sleep-emotion research has not been worthwhile. Instead, it is to validate the frustration in the field that even with a plenitude of studies on sleep and emotion, findings are spotty and inconclusive. Results on sleep and arousal tend to be more consistently replicated than findings on sleep and valence. This may be because valence and its shifts are represented too narrowly (e.g., Kalmbach and colleagues, 2014) and cannot compatibly integrate with data on arousal fluctuation across spectra (Armon, Melamed, & Vinokur, 2014; Bonnet & Arand, 2010).

Valence representation across a negative-neutral-positive continuum may best detect transition between emotional states that contribute to sleep and are affected by sleep. It is expected that low arousing emotion-driven behaviors that occur in the evening are most functional if done prior to sleeping. Positive valence of thought in the evening may also be important for sleep initiation, but it is expected that the pairing of low arousal and negatively valenced cognitive content could also be conducive to sleep. Within-person oscillation patterns characterized by low levels of pre-sleep arousal and high levels of post-sleep arousal is expected to be an important health measure for detecting vulnerability to insomnia. Behavior that aligns with this trajectory is expected to be conducive to sleep onset and to yield increased pleasure through sleep as a primary reinforcer.

This study takes the position that waking arousal is more predictive of sleep than waking valence is predictive of sleep. It is expected that good sleep would involve transition from a higher level of arousal in daytime to a lower level of arousal in the evening (de Zambotti et al., 2019; van Dalfsen & Markus, 2018; Yang, Lin, & Spielman, 2004). Biological evidence suggests that arousal deviations from this trajectory (e.g., low levels of morning arousal, flattened arousal trajectory; Bradley & Lang, 1994; Lang, 1980) from morning to evening relate to poor sleep (Bei, Seeman, Carroll, & Wiley, 2017; Van Lenten & Doane, 2016). Additionally, good sleep quality may facilitate pro-positive emotional transition from the pre-sleep period to the post-sleep period. This evening to morning trajectory of change across the emotional valence dimension would reflect an effect of sleep on emotional well-being and vice versa (Ong, 2017; Ong, Carde, Gross, & Manber, 2011; Ong et al., 2013). These two transitional patterns may be foundational reciprocal mechanisms characterizing the psychology of sleep. Deviations from these transitional patterns may indicate etiological risk for insomnia development.

The proposed study's aim is to test how a dimensional model of emotion integrates with a healthy model of sleep. The anticipated patterns can be depicted along the two-dimensional circumplex framework. One expectation is that experiences characterized by day-to-evening de-arousal (top-to-bottom rotation along the y-axis) would predict more efficient sleep initiation. Another expectation is that better sleep quality would predict day-to-day emotional shift toward positive internal experience (left-to-right rotation along the x-axis). A three-dimensional model of sleep-emotion fluctuation may best illustrate how individuals transition between waking emotional states to encourage healthy wake-sleep oscillation; this modeling may be a future endeavor. The current investigation prioritizes confirmation of reciprocally related trends in sleep-emotion research. This empirical synthesis is intended help the field calibrate priorities based on integrated knowledge about sleep, emotion, and mechanisms of regulation.

Emotional arousal and sleep. Perception of arousal is an important component involved in emotional arousal, which includes a general appraisal of internal activation. Emotional arousal is a functionally distinct construct that is central to an emotional experience and requires effective regulation (e.g., tolerating distress until the intensity of sensations and appraisals pass; Linehan, 2015). Adaptively regulated fluctuations in arousal can promote functional activation and de-activation involved in healthy living.

Post-sleep arousal seems important for optimal daytime functioning and alertness (Fisk et al., 2018). Post-sleep consumption of activating substances like caffeine may reflect the healthy propensity for people to want to feel alert in the morning; conversely, consumption in the evening can be dysfunctional for sleep (Kerpershoek et al., 2018). Pre-sleep arousal is a leading construct involved directly in sleep delay and indirectly in poor sleep quality (Shoji, McCrae, & Dautovich, 2014; Tavernier et al., 2016; Tousignant et al., 2018). Successful sleep-wake

regulation tends to include evening de-arousal (Feige et al., 2019; Krone et al., 2017; Sunnhed & Jansson-Frojmark, 2015).

Behavioral modifications involved in de-arousal have been found to be associated with better sleep. Examples of these behaviors include practicing mindfulness (Ong et al., 2017); ceasing late-day consumption of arousal-promoting substances, such as caffeine (Schutte-Rodin et al., 2008); ceasing late-day consumption of substances that initially decrease arousal but yield a mid-night rebound effect of increased arousal, such as alcohol (Vitiello, 1997); and minimizing environmental overstimulation, such as loud noise and exceedingly hot or cold environments (Muzet, 2007; Muzet, Libert, & Candas, 1984). These behaviors and more can promote internal regulation toward emotional calmness rather than emotional arousal as bedtime approaches.

It is likely that the natural downregulation of emotional arousal toward the pre-sleep period may both be conducive to initiating sleep efficiently as well as benefitting from that sleep during the night. Arousal reduction has been identified as a mediator of the effect of CBT-i on waking functional improvements (Sunnhed & Jansson-Frojmark, 2015). However, some evidence suggests that pre-sleep arousal alone does not predict sleep onset latency (Cervena, Espa, Perogamvros, Perrig, Merica, & Ibanez, 2014). The importance of the de-arousal process was articulated three decades ago (Sewitch, 1987), but no published research has examined the de-arousal process embedded within a circadian paradigm. Remarkable activation mechanisms occur throughout waking and sleeping periods (e.g., consider the idiosyncratic nature of sleep architecture; Siegel, 2004). The experience of having sleep architecture that fluctuates in alignment with sleep onset (evening transition) and waking time (morning transition) may contribute to morning functioning through high arousal and positive valence.

The longstanding empirical challenge identifying behavioral themes that predict good sleep suggests that behavioral health researchers could improve how they conceptualize sleep process constructs. Rather than studying behaviors themselves that promote optimal sleep, why not keep the behavior constant (i.e., self-reporting via survey) and assess how internal processes of emotion underlie specific behavioral trends implicated in poor sleep hygiene. It may be most direct to study the contributory emotional shifts that healthy sleepers facilitate through introspection, arousal regulation, and cognitive appraisal. Confirmation of this information about healthy sleepers can serve as a comparison point for clinical insomnia treatment research.

Emotional valence and sleep. The nature of reciprocal relation between sleep and emotional valence has not been clarified but cumulating evidence confirms a close interplay between sleep and valence (e.g., Feige et al., 2019; Vandekerckhove et al., 2012). Ongoing explorations of sleep-valence dynamics seem to be revealing that poor sleep affects emotional processing (Kahn et al., 2013; Walker & van der Helm, 2009) and predicts attentional bias toward negative stimuli rather than positive or neutral stimuli (Anderson & Platten, 2011; Barclay & Ellis, 2013; Takano, Vanden Poel, & Raes, 2018). Good sleep seems to predict next-day increased positive emotion and decreased negative emotion (Bouwmans et al., 2017; Nota & Coles, 2018). This seems to be a predominant mechanism involved in sleep-wake transition; however, pre-sleep valence does not seem to predict sleep (Bouwmans et al., 2017). However, These time-dependent patterns need to be directly investigated.

As a primary reinforcer, sleep is expected to elicit pleasure and behavioral regulatory patterns that encourage subsequent sleep and thus subsequent pleasure (Kalmbach et al., 2014; Rial et al., 2018). Biological studies suggest that someone’s inclination toward positivity during waking decreases from morning to evening through dopamine reductions; inclination toward

positivity is then enhanced across the sleep period into the morning as dopamine is replenished (Gottesman, 2002; Oishi & Lazarus, 2017; Rial et al., 2018). Establishing behavioral measures that reflect this cyclic timing would be helpful for the field. Correlational studies have indicated that people with generally high levels of positive affect tend to have more refreshing sleep (Fosse, Stickgold, & Hobson, 2001; Steptoe, O'Donnell, Marmot, & Wardle, 2008) whereas people who have difficulty regulating positive emotion tend to have poorer sleep (Ong et al., 2013; Talbot, Hairston, Eidelman, Gruber, & Harvey, 2009). There do not seem to be any well-designed longitudinal studies that reveal information about state relationships between positive emotion and sleep (Ong, Kim, Young, & Steptoe, 2017).

Researchers surmise that greater sleep quality has a buffering effect on emotional well-being such that it encourages greater positive emotion and less negative emotion (Wichers et al., 2007). Further, a ratio of higher positive emotion to lower negative emotion is a definitional component of emotional well-being (Hot et al., 2015; Kahn, Sheppes, & Sadeh, 2013). Therefore, a measure that allows depiction of shifting positive-negative ratio and buffering is needed to understand dynamic sleep-wake relation. Rather than assessing positive valence and negative valence on two orthogonal continua as is common (e.g., Bouwmans et al., 2017; Shen, van Schie, Ditchburn, Brook, & Bei, 2018; Kalmbach et al., 2014), it is more appropriate to use a measure depicting valence shifts along continuous metric. This dimensional depiction is amenable to the detection of unique patterns of pre-sleep to post-sleep change toward positive emotion as predicted by sleep quality.

Subjective sleep quality is the sleep variable with strongest empirical support for predicting next-day valence change. Bouwmans and colleagues (2017) conducted a novel examination of multilevel temporal relationships between sleep and affect. For up to 30 days,

healthy participants reported in the morning, afternoon, and evening about sleep and affect as well as other measures like fatigue. Assessment timing and influence on subsequent reports were not controlled for directly. Primary findings indicated that pre-sleep valence did not predict sleep variables but that sleep quality predicted next-day increase in positive emotion and decrease in negative emotion. These findings align with our rationale for the current study's second hypothesis and it is expected that our study will offer a replication of that by Bouwmans and colleagues (2017). It is also expected that the current study will address the sample size limitations (n = 27, insufficient for multilevel modeling) from Bouwmans and colleagues' study.

In another naturalistic study, de Wild-Hartmann and colleagues (2013) examined bidirectional associations between sleep diary variables and affective states, without referencing a specific measure. The primary finding was that sleep quality, specifically, related to next-day positive affect. The authors did not interpret this finding, and some have speculated that it may be because de Wild-Hartmann and colleagues (2013) considered the finding to be spurious (p. 238). The current study design assumes an opposite interpretation, that the effect of high sleep quality on increased positive emotion, and potentially reduced negative emotion, may actually be a *core tenet* to understanding the human experience rather than an outlier finding. There is increasing evidence that the effect of sleep quality on post-sleep valence is a leading mechanistic pathway to healthy emotional response patterns involved in adaptive sleep-wake transitions. As mentioned, confirmations of this pattern are relatively recent and need to be directly tested.

Sleep Parameters (3)

The combined study of *sleep onset latency* (i.e., time taken to fall asleep after someone begins attempting to fall asleep) and *sleep quality* (i.e., how refreshed someone feels upon wakening) provides foundational daily pre-sleep and post-sleep demarcation, respectively,

necessary for understanding coherency in subjective sleep reporting and representation (Hu, Wang, Sun, Arteta-Garcia, & Purol, 2018). That is, sleep onset latency and sleep quality represent proverbial bookends of sleep momentum driving adaptive human functioning. Although other subjective criteria (e.g., sleep duration, waking after sleep onset) experienced during the night may be important for understanding diversity in presentation of insomnia-related problems, they are not the focus of this initial investigation because sleep onset latency and sleep quality seem to reflect more important indicators of health (Blake, Trinder, & Allen, 2018; Buysse, Reynolds, Monk, & Berman, 1989; Gruber, Paquin, Cassoff, & Wise, 2015, p. 400).

Sleep onset latency (SOL) is a term that traditionally refers to the amount of time in minutes that it takes someone to fall asleep initially. It is a primary component involved in the calculation of sleep duration (Carney et al., 2012). SOL delay is considered especially threatening because sleep duration becomes truncated and the person may have a strict wake time (e.g., to start the workday). SOL is represented on a continuous scale, naturally fluctuates, and its variability is involved in insomnia etiology (Molzof et al., 2018; Richardson, Gradisar, & Pulford, 2015). Considering that insomnia symptoms are related to excessive time awake in bed, efficient healthy SOL likely involves limited time spent awake in bed. Someone who begins the process of preparing for sleep prior to getting into bed, and then gets into bed when the sleep urge intensifies, will experience short SOL. This notion is consistent with the efficacious behavioral sleep restriction strategy used in insomnia treatment (Dong, Soehner, Belanger, Morin, & Harvey, 2018). As such, to calculate SOL the current study will both assess when participants begin to prepare for bedtime and when participants begin to attempt to fall asleep.

Research on prolonged SOL has demonstrated that arousal is an influential variable; de-arousal seems to be required to immerse into a sleep state (Tousignant, Taylor, Suvak, &

Fireman, 2018; Richardson et al., 2015). Pre-sleep arousal components of cognitive activation (e.g., excessive thoughts) and bodily activation (e.g., racing heart) predict delayed sleep onset (Palagini, Mauri, Dell'Osso, Riemann, & Drake, 2016; Tousignant et al., 2018). This two-factor model mimics the cognitive-somatic representation of constructionist emotion theories (e.g., James, 1884; Lazarus, 1991; Lindquist, 2013; Russell & Mehrabian, 1974; Schachter & Singer, 1962). This suggests that the way that people represent or construct their emotions would naturally relate to sleep experience.

Sleep quality is a critical post-sleep subjective variable for advancing sleep-emotion research. It mediates the effect of objective sleep on enduring emotional states (Bei et al., 2015; Bei et al., 2017). When compared to sleep duration, sleep quality better represents the psychology of sleep experience (Bathgate, Edinger, Wyatt, & Krystal, 2016; Tavernier and Willoughby, 2014). It also relates more closely to valence than sleep duration does (Shen, Schie, Ditchburn, Brook, & Bei, 2018). Researchers have not reached consensus about the best way to operationalize subjective sleep quality. There is temporal precedence for considering sleep quality to be a state construct that fluctuates and can be assessed by a one-item self-report measure to detect nuanced variability patterns (Tousignant et al., 2018; Winzeler et al., 2014). This daily sleep quality item has been found to be better at discriminating nuance in health compared to a multi-item self-report measure that inflates sleep quality scores (Carney et al., 2012; Hartmann, Carney, Lachowski, & Edinger, 2015). It is important to understand how appraisal processes can most favorably oscillate and can be restructured if someone is experiencing poor quality sleep. The process of framing an experience of sleep-dependent refreshment in the morning is linked to the appraisal of waking functioning (Garde et al., 2011;

Molzof et al., 2018; Semler & Harvey, 2006). The inherent perception involved in the sleep quality construct suggests its utility for insomnia research.

Emotion and Insomnia (4).

Compelling information about the nature of maladaptive sleep-wake behavioral regulation can be gleaned from the robust insomnia literature. Insomnia is characterized by dissatisfaction with the quality or quantity of sleep, difficulty initiating and/or maintaining sleep, disrupted sleep at least three nights per week for at least one month, and symptom-focused waking distress or impairment (American Psychiatric Association, 2013, pp. 362-363). Insomnia symptoms fluctuate along a non-clinical to clinical continuum and can develop into episodic or chronic manifestations (Ellis et al., 2012; Fairholme et al., 2013). There is evidence for increased likelihood of psychiatric issues depending on level of insomnia symptoms, and vice versa (Sarsour, Morin, Foley, Kalsekar, & Walsh, 2010; Smith, Huang, & Manber, 2005). Despite frequent comorbidity between insomnia and other psychiatric conditions, suggesting overlapping etiologies in sleep and emotional disorder, no published research has examined emotional patterns involved in insomnia.

Insomnia, emotion, and etiological mechanisms. Although emotional mechanisms of insomnia and healthy sleep have not been examined, other types of mechanisms involved in chronic insomnia disorder have been delineated and tested. These mechanisms represent insomnia as a psychologically based disorder characterized by cognition and behavior oriented toward sleep-related threat cues (Harvey, 2002). Psychological issues in sleep problems seem to be cyclically reinforcing (Harvey, 2002) and can be risk factors for a diverse range of negative health consequences of poor sleep (e.g., hypotension: McHugh, Fan, Kenny, & Lawlor, 2012; dementia: Pase et al., 2017; and vehicle accidents: Léger et al., 2014). Established psychological

mechanisms of sleep disruption include cognitive and somatic arousal (Nicassio, Mendlowitz, Fussell, & Petras, 1985; Winzeler et al., 2014), with cognitive arousal as the more powerful mechanism (Tousignant et al., 2018), as well as negatively valenced appraisals of sleep loss consequences (Baglioni et al., 2010; Harvey, 2002; Harvey, Gregory, & Bird, 2002; Harvey, Tang, & Browning, 2005; Jansson & Linton, 2007).

Emotion circumplex dimensions, which can portray waking emotion fluctuation patterns and their timing in relation to sleep process, may be important to consider in insomnia etiology. The pairing of positive valence with higher arousal in the evening or with lower arousal in the morning may signal incremental deviation from optimal sleep-wake behavioral health.
The literature needs to assess how valence-arousal combinations, comprising emotional experience, relate to insomnia. Building from the cognitive-behavioral tenet that emotional feelings reciprocally relate to thoughts and behaviors (Beck, 1972; Beck, Rush, Shaw, & Emery, 1979), this knowledge could substantiate a transdiagnostic model of episodic insomnia. Understanding how connections between emotional valence, emotional arousal, and sleep vary between people with satisfactory sleep versus people with unsatisfactory sleep may elucidate an important regulatory target for people deviating from healthy sleep patterns. The current study does not attempt to compare an emotional model of insomnia to the cognitive model of insomnia (Harvey, 2002). Rather, the current study is an initial attempt to understand the role of emotion within insomnia etiology.

Cognitive-behavioral therapy for insomnia (CBT-i) is the insomnia treatment with most empirical support (Karlin, Trockel, Taylor, Gimeno, & Manber, 2013; National Institutes of Health, 2005; Smith et al., 2002), yet it has low adherence rates and can have high attrition rates (Jansson-Frojmark & Norell-Clarke, 2018; Matthews, Arnedt, McCarthy, Cuddihy, & Aloia,

2013). These issues may be related to the treatment's underrepresentation of emotional experience involved in insomnia-based suffering. CBT-i prioritizes behavioral change, which is intended to improve sleep and well-being. The change requires the sleepy individual to stay awake past that person's usual bedtime. The time to allow sleep onset is determined by summating scores of time spent asleep in bed and dividing by total time in bed. The individual attempts to stay awake until that time, despite perceived sleep need.

Patients' adherence to leaving bed while awake at night has been identified as the primary mechanism that predicts posttreatment insomnia symptoms (Dong et al., 2018). After leaving bed it is expected that eventual potentiation of homeostatic sleep pressure will override waking activation (Borbely, 1982). The idea is that behavioral reshaping could lead to counterconditioning such that the patient associates the bedroom stimulus with a positive sleep experience rather than with a negative waking experience (Robertson, Broomfield, & Espie, 2007). However, there is a gap in knowledge about the psychology of this assumed transformation and how it relates to episodic insomnia experiences. Etiological models note insomnia manifestation as resulting from the pairing of the bedroom environment (unconditioned stimulus, US) with dysphoria about insomnia symptoms (conditioned stimuli, CS). This pairing manifests as a perceived lack of self-efficacy in sleep initiation (Suh et al., 2012). Therefore, behaviors that allow re-alignment in the wake-sleep cycle are needed for recovery from insomnia. More knowledge about how to supplement sleep restriction therapy with guided emotion modulatory approaches (i.e., arousal or valence modulation mechanisms) may improve efficacy and efficiency of CBT-i treatment.

The power of hedonically rewarding sleep (i.e., a primary reinforcer) is important to explore. The current researcher does not yet aim to delve into the content of specific thoughts

implicated in good and bad sleep (e.g., sleep-related thoughts, emotion-related thoughts, sporadic nonspecific thoughts). An aim of the current study is to increase the integrity of evidence supporting a pro-positive function of sleep. This sleep-dependent pull toward positive appraisal may be an anchor involved in insomnia recovery. Sleep restriction therapy through delayed bedtime may be involved in the positive pull involved in insomnia recovery.

Valence and arousal mechanisms have not been directly examined in CBT-i research, yet they are common targets of interventions in cognitive-behavioral transdiagnostic treatments. Valence and arousal changes are anticipated to be useful targets for typically healthy sleepers responding to waking emotional challenges (Keil & Miskovic, 2015, pp. 24-25). Additionally, cognitive reappraisal and arousal regulation are important mechanisms involved in treatment of psychopathology (e.g., Barlow et al., 2018; Kocovski, Fleming, Hawley, Ho, & Antony, 2015). Effective use of these strategies to facilitate sleep, a primary reinforcer, is expected to yield increased pleasurable experiences across time. Research suggests that the positive emotional effects of sleep may increase across the lifespan (Gui et al., 2018; Schwarz et al., 2018; Vermeulen, van der Heijden, Benjamins, Swaab, & Someren, 2017), suggesting mechanistic power of emotional valence in adults.

Sleep-emotion interplay and psychological disorder. Exploring the cyclical nature of emotional mechanisms that contribute to healthy sleep and episodic bouts of insomnia is important for understanding the foundational nature, onset, and course of psychologically based sleep disruption. This clarification allow better understanding of the bottom-up and top-down intersection in symptom development of psychologically based sleep disruption. Information about the relative interplay of emotional dimensions involved in sleep-emotion challenges could be useful for assessing change and outcomes indicative of functioning. It also could aid the

conceptualization process for comorbid insomnia disorder and emotional disorder, including understanding of its development and intervention opportunities for treatment.

Current approaches to nosology for studying psychological dynamics differ in the lens through which their proponents conceptualize the complexity of human suffering. The American Psychiatric Association employs a top-down approach to categorizing human experiences into symptom clusters, allowing for seemingly infinite combinations of symptom presentations. Deficient sleep and emotion difficulties each have been identified as common symptoms in many forms of psychopathology (Harvey, Murray, Chandler, & Soehner, 2011; Kring & Sloan, 2010). Intervention protocols have been developed to address select core combinations of emotional disorder symptoms, with promising transdiagnostic treatment approaches underway. For example, the development of the unified protocol for the transdiagnostic treatment of emotional disorders was based on evidence that people with emotional disorders have in common maladaptive emotional response patterns and a sense that emotions are out of their control (Barlow et al., 2018, p. vii). The implications of what it means for emotions to be out of control has been explored in relation to waking functioning. However, what it means to control one's emotions adaptively to initiate and benefit from sleep has not been explored.

Implementing a bottom-up approach to the study of human suffering, the Research Domain Criteria (RDoC) emphasizes the need for "systematic study of the nature of mental health and illness in terms of varying degrees of dysfunctions in general psychological systems" (NIMH, 2008). The RDoC matrix identifies six constructs or systems of interest including arousal, positive valence, and negative valence as three of them. Therefore, the current research on the interplay of sleep-related change, valence-related change, and arousal-related change may

reveal that disparate emotional response patterns correspond with disparate levels of insomnia symptom severity.

Moreover, RDoC calls for increased understanding of self-report and behavior units of analysis as they relate to research and intervention, warranting more sophisticated use of empirically supported subjective assessments. Responding to this call, the current study is designed to allow plotting of interrelationships across pre-sleep and post-sleep intervals and in relation to a continuous measure of insomnia symptom severity. Results from this multilevel study will advance scientists' understanding of core experiences governing functional sleep-emotion relation and etiological risk for insomnia. To clarify, the current study does not directly assess diagnoses of emotional disorders that may co-occur with insomnia symptoms. However, it does assess sleep dysfunctional emotional patterns across the waking period, which may offer clues into how insomnia and emotional disorders can comorbidly manifest.

Advancing the standards of sleep-emotion research (5)

The current study's novel approach is to examine how an emotional circumplex conceptualization of how psychological processes operate in healthy sleepers compared to people with episodic insomnia. This is the first study to model iterations of sleep-emotion operation involved in health. It is also the first study to examine how etiological iteration patterns are involved in insomnia. One published study purported that their design and analysis represented the relationship between insomnia and emotion; however, their representation of emotion was narrow and not grounded in theory (i.e., participants rated their level of "emotional balance;" Feige et al., 2019). Another study (Ong, Carde, Gross, & Manber, 2011) examined cross-sectional relationships of valence and arousal patterns among people who identified as good sleepers and bad sleepers, reflecting a potential fit between circumplex emotional theory

and sleep theory. They find that people with poor sleep quality had greater negative affect during the day and greater arousal and negative affect at night (Ong et al., 2011), but this cross-sectional association needs to be replicated with a more sophisticated design. Researchers could detect greater nuance of experience by assessing daily sleep problems prospectively rather than assessing the past month's sleep (Buysse et al., 1989) at one time point. This also could minimize the influence of retrospective memory bias on self-reporting. Another form of expansion is to analyze prospective measurements, taken twice per day, at functionally distinct times (morning and evening), for a longer duration (e.g., 2-3 weeks).

Given the plethora of disunified sleep-emotion research findings (see Babson & Feldner, 2015; Moss, Lachowski, & Carney, 2013), prudent and economical research will focus on clarifying daily emotion variables that relate to nightly sleep. Changes in feelings of arousal and pleasantness, and one's representation of these change trajectories, may have functionally specific relationships to sleep quality and sleep onset. These constructs and their relation are integral to functional well-being and recovery from insomnia (Dentico et al., 2016; Penberthy et al., 2017; Ong, Shapiro, & Manber, 2008). With an undetected depth and breadth of dimensions to the human experience and psyche, these two dimensions have been empirically confirmed and may be central to continuity of experience. Therefore, modeling dynamic change in arousal and valence could advance scientific philosophical knowledge about the human experience. To accurately depicting sleep-emotion process, certain issues should be addressed.

One issue is that the time intervals across which variables are computed often lack theoretical rationale and undermine data alignment (e.g., Galambos, Dalton, & Maggs, 2009). It is rare that daily data is collected. When daily data has been collected it is coded in odd ways that narrow the meaning of results. For example, the 2014 study by Kalmbach and colleagues

calculated an average of sleep quality across three nights as a predictor of positive affect. They did not specify how positive affect was calculated. Additionally, many studies ask about the previous 24-hour period, which can bias results. Fragmented forms of data collection like these, often those without theoretical rationale, limit the degree to which researchers can make claims about the functional specificity of sleep-wake variables. The current procedure is designed to examine functional specificity of emotional dimension in predicting sleep as well as to examine functional specificity of sleep in predicting waking emotional dimension.

Another issue is that research is limited by uncertainty how best to order sleep-emotion measurement to caution against a reporting bias of the first report on the second report. This has contributed to the literature having many more crude than nuanced sleep-emotion investigations. Rather than avoiding the pairing of sleep-emotion measures because of uncertainty about how timing of administration affects results, it seems about time that the uncertainty is addressed. It may be the case that the behavioral act of reporting first about sleep or emotion powerfully influences the subsequent behavioral act of reporting about emotion or sleep, respectively. Understanding how self-report framing predicts self-report outcomes is important for advancing the degree of nuance with which researchers understand reciprocal sleep-emotion influence. This question seems best addressed during morning assessment periods because sleep experiences are in recent memory while the individual may also be reflecting and preparing emotionally to face the day.

A third salient issue in sleep-wake designs is that *cyclical* change actually has not been examined. Some researchers claim to examine cyclic process, but a close read between the lines of designs suggests otherwise. For example, in their attempt to assess the sleep-arousal cycle across three days, Garde, Albertsen, Persson, Hansen, & Rugulies (2012) measured arousal in the

pre-sleep period during days 1 and 2 and they measured sleep in the post-sleep period during days 2 and 3. This is one example among many of how methods and analysis can disjoint the representation of sleep-emotion continuity. Erroneously purporting to measure bidirectionality in arousal-sleep relation, they noted that higher pre-sleep arousal ratings were associated with poor sleep whereas poor sleep ratings were associated with higher ratings of waking stress described as arousal. Additionally, they did not use a measure that taps emotional arousal or valence constructs but instead seems to tap stress and energy-related constructs in addition to valence; this approach lacks theoretical underpinning. However, the authors tack on their non-theoretically grounded valence findings and suggest that negative emotion is especially involved in this unfavorable vicious “circle.” Language like this is misleading.

Regarding this third limitation in the field, de Wild-Hartmann (2013) attempted to assess the sleep-valence cycle by measuring affect 10 times throughout during waking and measured sleep twice during waking for up to five days. They found that sleep was a stronger predictor of affect than affect was of sleep. However, the imbalance in daily cumulative sleep-affect ratings suggest measurement error that cannot be accounted for on a bidirectional basis. Additionally, their non-dimensional, non-theoretically grounded affect measure could not assess rotation (i.e., continuous transitional change) to the same degree that the current study design allows. Balance in design elements (e.g., measurement units and intervals, timing of assessments, numbers and combinations of delta change parameters) maintains the empirical integrity necessary for capturing continuity and internal process.

Proposed Cycle of Interest (6)

The current study is designed to reveal a theoretically grounded sleep-emotion cycle that can portray emotional continuity across daily and nightly transitions. Themes in research

evidence inform the tenets of this cycle. Pre-sleep arousal is a bifactorial construct often dichotomized into cognitive arousal and somatic arousal and examined in relation to sleep. Pre-sleep arousal has been described as a variable that prolongs time to fall asleep from when someone intends to initiate sleep onset. The current study takes a constructionist approach to studying, instead, a unifactorial construct of pre-sleep emotional arousal involved in SOL. Further, research demonstrates that pre-sleep arousal predicts sleep quality, and that cognitive arousal is especially influential in this mediation. This suggests involvement of an appraisal mechanisms—perhaps appraisal of arousal and appraisal of valence—involved in the governance of the sleep-wake cycle. Recent evidence suggests that sleep quality is associated with more positive waking emotion and less negative waking emotion; this daily dynamic needs to be replicated directly. Greater positive emotion and less negative emotion signifies emotional well-being, a leading indicator of psychological health. Coming full circle, the healthiest covarying occurrences will include (a) high arousal and positive valence in the morning and (b) low arousal and neutral-positive valence in the evening. These patterns would reflect healthy morning activation and dopamine spike, evening calmness and dopamine release, and quality sleep and pro-positive valence change across the sleep period. These mechanistic patterns of emotional oscillation may mirror biological mechanistic patterns and indicate how psychological propensity contributes to functioning and survival as a species.

Acknowledgements

I am grateful for the opportunity to complete this doctoral dissertation. I appreciate that Dr. Amy Marks joined my dissertation committee, and I enjoyed hearing her perspective on the study results and future directions. Conversely in valence, it is with a heavy heart that the dissertation completion occurred in the absence of Dr. Michael Suvak. His mentorship was pivotal and instrumental for my pursuit of the dissertation's statistical analysis. He is missed. I recently learned that Michael also studied the circumplex model in his dissertation.

I am immensely grateful to those committee members involved in the full trajectory of this project. During my first semester of the Clinical Psychology Ph.D. program, I learned from Dr. Gabrielle Liverant about the evidence-base of adult psychopathology and its transdiagnostic emotional components. As my program advisor and mentor-colleague, Gaby continues to inspire me to advance empirical knowledge and its integration within education and clinical practice.

Dr. Fireman's primary mentorship and collaboration have been integral to my development and growth, achievement, and enjoyment of the doctoral candidacy process. Gary, thank you for your relationship in pursuit of joy, laughter, fun, and positive impact as scholars and psychological scientists. Your mentorship continues to set me on a trajectory of my dreams professionally and personally. Thank you to my labmate siblings, and to my graduate institutional home Suffolk University.

I love and appreciate so many humans. Thank you mom for introducing me to the intersection of art and science. Thank you Hayden for trusting my short-term decision making for reaching our longer term goals. Thank you Sarah for welcoming so many sleepovers. Thank you to all who join me in wrestling to understand complex psychological topics across our lifespans, with optimism and zest. May peace and good sleep be with you all. Life is good.