LONGITUDAL DYADIC ASSOCIATIONS BETWEEN FEAR OF CANCER RECURRENCE AND OBJECTIVE SLEEP DISTURBANCE: BREAST CANCER SURVIVORS AND PARTNERS IN THE FIRST-YEAR POST-DIAGNOSIS

by

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A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychological & Brain Sciences

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ABSTRACT

Background: Sleep disturbance is common among breast cancer (BC) survivors. Partners of BC survivors also experience sleep disturbance and sleep is concordant within-couple. Fear of cancer recurrence (FCR) is related to self-reported sleep disturbance in BC survivors and partners. Yet, no studies have examined the relationship between FCR and objective sleep disturbance in BC survivors, their partners, or at the dyad level. The present study examined the relationship between FCR and objective sleep disturbance in couples coping with early-stage BC. We hypothesized that greater FCR is associated with greater objective sleep disturbance. **Methods:** In two, 21-day daily diary periods (the completion of adjuvant treatment and the first post-treatment mammogram), BC survivors and partners reported daily FCR and actigraphy-measured objective sleep disturbance. Multilevel dyadic path and actor-partner interdependence modeling estimated daily, within-person and within-couple associations between one's own FCR and one's own sleep disturbance (actor effects) as well as between one's own FCR and one's partner's sleep disturbance (cross-partner effects). **Results:** At the first, post-treatment mammogram, on a day that a survivor reported more FCR than was typical for them, they also demonstrated shorter sleep period length and shorter total sleep time that night, after controlling for any daytime sleep from that same day. Otherwise, FCR was not significantly related to objective sleep disturbance, in both periods, for survivors or partners, actor or cross-partner effects. **Conclusions:** Across early survivorship, BC survivors and partners demonstrated elevated levels of objective sleep disturbance – particularly difficulties

with sleep maintenance. However, findings suggest that FCR is not consistently linked to objective sleep disturbance in couples coping with early-stage BC.

Chapter 1

INTRODUCTION

In the U.S. alone, there are greater than 3.8 million breast cancer (BC) survivors (Miller et al., 2019). This population is growing (American Cancer Society, 2019) and this growth is attributed to both increasing incidence (Howlader et al., 2020) and decreasing mortality (American Cancer Society, 2019). The increasing incidence is driven by a rise in early-, not late-stage disease (American Cancer Society, 2019). Taken together, the increase in incidence and decrease in mortality has resulted in a large population of BC survivors and more so, early-stage BC survivors.

Sleep Disturbance among BC Survivors

The prevalence of sleep disturbance and insomnia disorder is greater for BC survivors as compared to both survivors of other cancer types and the general population (J. Savard et al., 2001, 2009, 2011). Here, "sleep disturbance" will refer to a heterogeneous set of sleep difficulties including dissatisfaction with sleep quantity, poor sleep quality, difficulty falling asleep, and trouble staying asleep through nocturnal or early-morning awakenings (Berger, Sankaranarayanan, et al., 2007). For insomnia disorder to be diagnosed, these sleep difficulties must occur at least 3 nights per week, for at least 3 months (American Psychiatric Association et al., 2013). Sleep difficulties are often related to one another but can also exist on their own (Léger et al., 2010; T. Roth et al., 2010; Sarsour et al., 2010; Wilkinson & Shapiro, 2012). For

example, individuals can report dissatisfaction with their sleep quality, despite adequate sleep duration (Wilkinson & Shapiro, 2012).

Prevalence estimates for insomnia disorder and sleep disturbance among BC survivors vary depending on the study design and methods but have been demonstrated using both self-report and objective measures (e.g., polysomnography, actigraphy) of sleep (Budhrani et al., 2015). A longitudinal study of insomnia comorbid with cancer found that 36% of BC survivors met criteria for insomnia disorder and an additional 33% reported sleep disturbance not meeting full criteria for insomnia disorder during the perioperative phase (J. Savard et al., 2009, 2011). For comparison, in that same study, the prevalence for insomnia disorder was 29% among gynecological, 28% among urinary or gastrointestinal, 25% among head and neck, and 15% among prostate cancer survivors (J. Savard et al., 2011). In contrast, the prevalence of insomnia disorder in the general population is estimated to be 10% (National Institute of Health, 2005).

Sleep disturbance among BC survivors is not limited to diagnosis and treatment. Instead, 42% of BC survivors either meet criteria for insomnia disorder or report sleep disturbance 18-months post-surgery (J. Savard et al., 2009, 2011). When compared to healthy, age-matched controls, BC survivors five years post-treatment report significantly more sleep disturbance (Otte et al., 2010). Taken together, evidence suggests that for a significant portion of BC survivors, sleep disturbance is severe and chronic.

The 3-P (Morin, 1993; Spielman, 1986) and cognitive models (Harvey, 2002) are the most widely accepted frameworks for insomnia disorder. These models propose that predisposing factors, such as hyperarousal, cause some individuals to be at greater risk for insomnia disorder. Predisposing factors together with precipitating events, such as stressful life events including illness, result in initial sleep disturbance. Initial sleep disturbance that is maintained by maladaptive cognitions (e.g., worrying about the potential consequences of poor sleep) and maladaptive sleep behaviors (e.g., napping) results in insomnia.

Factors associated with or consequences of BC diagnosis, treatment, and survivorship may serve as contributing factors for sleep disturbance, potentially explaining the increased prevalence among this population. For example, the diagnosis and associated distress may serve as precipitating factors. In a study of women recently diagnosed with BC, 88% reported sleep disturbance following diagnosis but even before surgery and 50% reported moderate to high levels of distress associated with that sleep disturbance (Cimprich, 1999). Evidence from both self-report and objective measures suggests that sleep is already disturbed prior to adjuvant treatment (Ancoli-Israel et al., 2006, 2006; Berger, Farr, et al., 2007; Dhruva et al., 2012). Adjuvant treatment and resulting distress, direct physical and psychological effects, and side effects (e.g., nausea, pain) may also serve as contributors. Longitudinal research provides evidence that sleep disturbance, as measured by both self-report and objective measures, worsens across both chemotherapy and radiation for BC survivors (Ancoli-Israel et al., 2014; Dhruva, Paul, et al., 2012). A systematic review of the

impact of BC treatments on sleep disturbance concluded that women who undergo adjuvant treatment, particularly chemotherapy, report greater levels of sleep disturbance as compared to women not treated with adjuvant therapy (Costa et al., 2014).

As previously mentioned, sleep disturbance is more prevalent among BC survivors as compared to survivors of other cancer types (J. Savard et al., 2009, 2011). Despite female sex being a predisposing factor for insomnia disorder (Zhang & Wing, 2006), the increased prevalence of sleep disturbance among BC survivors is not solely attributable to sex (J. Savard et al., 2009, 2011). Vasomotor symptoms (e.g., nighttime hot flashes, night sweats) resulting from the discontinuation of hormone replacements, chemotherapy, and/or adjuvant hormonal therapy may be unique precipitating and perpetuating factors for BC survivors specifically. Assessed via both self-report and objective measures, BC survivors experience more nighttime hot flashes as compared to age-matched controls and these hot flashes are longer, more severe, and more distressing (Carpenter et al., 2004, 2007). Nighttime hot flashes and sleep disturbance, both measured via objective measures, occur concurrently in BC survivors (J. Savard et al., 2004; M.-H. Savard et al., 2013). In sum, the correlates and consequences of the BC trajectory may contribute to the increased prevalence of sleep disturbance for survivors. Indeed, 58% of BC survivors with sleep disturbance report that this sleep disturbance was either caused or made worse by their BC (J. Savard et al., 2001).

Sleep Disturbance among Partners of BC Survivors

Both psychosocial adaptation to cancer and sleep disturbance are increasingly examined from a dyadic perspective (Chan et al., 2017; Kayser et al., 2007; Otto et al., 2019; Troxel et al., 2007). Intimate partners experience comparable levels of distress to survivors across BC diagnosis, treatment, and survivorship (Baider et al., 2003; Manne et al., 2007; Northouse et al., 1998; Walker, 1997). Studies of couples coping with BC provide evidence for psychosocial adjustment being interdependent across the BC trajectory (Ben-Zur et al., 2001; Kim et al., 2008; Segrin et al., 2007; Segrin & Badger, 2014). In addition, although relatively less studied, evidence with self-report measures of sleep suggests that partners of BC survivors also experience elevated levels of sleep disturbance (Chang et al., 2007; Dhruva, Lee, et al., 2012). We are aware of no published studies to assess objective sleep disturbance in the partners of BC survivors specifically. However, elevated levels of objective sleep disturbance have been demonstrated in family caregivers, including spouses/partners, for survivors of mixed cancer types (Carney et al., 2011). Moreover, 63% of U.S. adults report sharing the same bed with an intimate partner (National Sleep Foundation, 2012) and prior work with both self-report and objective measures suggests that sleep is concordant within couples, including in couples coping with cancer (Carney et al., 2011; Gunn et al., 2015; Lee et al., 2018; Meadows et al., 2009). For example, in a study of objective sleep disturbance among cancer survivors (including BC survivors) and their family caregivers, most of which were spouses/partners, time spent in bed, total sleep time, number of awakenings, wake after sleep onset, and sleep efficiency

were significantly, positively, and strongly correlated within dyads (Carney et al., 2011). In this same study, survivors' mean sleep efficiency was significantly poorer than that of partners. However, apart from sleep efficiency, there were no significant differences between the mean objective sleep disturbance outcomes for survivors and family caregivers.

Correlates and Consequences of Sleep Disturbance

Sleep disturbance is implicated in a multitude of mental and physical health outcomes for BC survivors specifically and the general population alike. To narrow the scope, this section will focus on the mental and physical health outcomes particularly impacted by BC, but to which sleep disturbance in the general population is also related.

Depression, fatigue, and cognitive impairment are among the most reported side effects of BC diagnosis and treatment (Bower, 2008) and each is more prevalent among BC survivors, including in long-term survivors, as compared to women without a history of BC (Ancoli-Israel et al., 2014; Bower et al., 2000; Janelsins et al., 2017; Maass et al., 2015; Minton & Stone, 2008). Sleep disturbance is associated with depression, fatigue, and cognitive impairment in BC survivors (Ancoli-Israel et al., 2006; Bardwell et al., 2008; Bower et al., 2011; Caplette-Gingras et al., 2013; Carpenter et al., 2004; Dhruva, Paul, et al., 2012; Sanford et al., 2014). Relevant to partners of BC survivors, sleep disturbance is also associated with depression (Alvaro et al., 2013; Hertenstein et al., 2019; Li et al., 2016), fatigue, (T. Roth & Ancoli-Israel,

1999), and cognitive impairment (Fortier-Brochu et al., 2012; Fortier-Brochu & Morin, 2014; T. Roth & Ancoli-Israel, 1999) in the general population.

Regarding physical health, the majority of both BC survivors (Sabiston et al., 2014) and the general population do not meet recommendations for physical activity (Carlson et al., 2010). Sleep disturbance is associated with lower levels of physical activity among BC survivors (Bernard et al., 2016; Colagiuri et al., 2011) and the general population (Kline, 2014). Compared to women without a history of BC, BC survivors, including those with early-stage disease, are at increased risk for cardiovascular disease and cardiovascular disease mortality (Abdel-Qadir et al., 2017; Gernaat et al., 2017; Mehta Laxmi S. et al., 2018). For some BC survivors, the ten-year risk for cardiovascular disease is equal to or greater than the ten-year risk for BC recurrence (Bardia et al., 2012) with cardiovascular disease and BC being the top causes of death for this population (Abdel-Qadir et al., 2017; Patnaik et al., 2011). We are aware of no current studies on the relationship between sleep disturbance and cardiovascular disease risk and mortality in BC survivors specifically. However, sleep disturbance is predictive of all-cause mortality in BC survivors (Trudel-Fitzgerald et al., 2017) and sleep disturbance is predictive of cardiovascular disease risk, cardiovascular disease mortality, and all-cause mortality in the general population (Ge et al., 2019; Javaheri & Redline, 2017).

Interim Summary

As an interim summary, both BC survivors and their partners experience elevated levels of sleep disturbance, which is related to important mental and physical health outcomes for BC survivors specifically and the general population alike. Following from this, it is important to understand the contributing factors for sleep disturbance for couples coping with BC and particularly, couples coping with early-stage BC, as this is a growing population. Past research on contributors for sleep disturbance in BC survivors has focused on sociodemographic (e.g., age), disease (e.g., stage), and treatment characteristics (e.g., adjuvant treatment type) or factors not specific to cancer (e.g., psychological distress; Bardwell et al., 2008; Costa et al., 2014; Otte et al., 2010). While sleep disturbance among partners of BC survivors has been less studied, sociodemographic characteristics and psychological distress have been shown to be related to the sleep disturbance of partners of survivors with other cancer types (Chan et al., 2017; Chang et al., 2007; Otto et al., 2019). For example, in a study of advanced cancer survivors and their partners, survivors' anxiety was negatively associated with their own as well as their partner's self-reported sleep duration and vice versa (e.g., partner's anxiety negatively impacting survivor's sleep; Otto et al., 2019). While informative, sociodemographic, disease, and treatment characteristics are unmodifiable and therefore cannot serve as intervention targets for sleep disturbance among couples coping with BC. Additionally, given the increased prevalence of sleep disturbance among couples coping with cancer, cancer-specific factors may be unique contributors for this population. A integrative review of

subjective and objective measures of sleep disturbance in BC survivors called for future research on the cancer-specific factors, including psychological factors, that contribute to sleep disturbance in this population (Budhrani et al., 2015).

Fear of Cancer Recurrence: A Common Concern Among BC Survivors and Partners

Psychological theory together with recent research suggests that fear of cancer recurrence (FCR) may be one such modifiable, cancer-specific contributor for sleep disturbance among BC survivors and their partners. FCR is defined as the "fear, worry or concern relating to the possibility that cancer will come back or progress," (Lebel et al., 2016, p. 3266; Sharpe et al., 2017). FCR is reported by both early-stage BC survivors and their partners (Perndorfer et al., 2019; Simard et al., 2013; Soriano et al., 2019, 2021; Soriano, Pasipanodya, et al., 2018; Soriano, Perndorfer, et al., 2018) and is interdependent within couple (Mellon et al., 2006, 2007). Clinical or high levels of FCR have been reported for BC survivors and their partners both in early (Perndorfer et al., 2019) and long-term survivorship (Cohee et al., 2017; Mehnert et al., 2009), suggesting that FCR is a chronic concern for these couples.

FCR and Sleep Disturbance: Theoretical Rationale

To our knowledge, eight theoretical models exist for FCR (Curran et al., 2017; Fardell et al., 2016; Heathcote & Eccleston, 2017; Lebel et al., 2018; Lee-Jones et al., 1997; Maheu et al., 2019; Mellon et al., 2007; Simonelli et al., 2016) and these models overlap considerably (Curran et al., 2017). The framework by Lee-Jones and

colleagues (Lee-Jones et al., 1997) is both the first and most cited model (Custers et al., 2017) and so will be used as an exemplar.

According to the framework by Lee-Jones and colleagues (1997), internal (e.g., somatic symptoms) and external (e.g., post-treatment mammograms) reminders of cancer and the possibility of recurrence serve as antecedents for FCR. These antecedents or triggers are interpreted according to one's cancer-related beliefs (e.g., past experience with cancer, knowledge about risk of recurrence) resulting in one's perception of risk of recurrence and associated anxiety/worry, rumination, and intrusive thoughts, together influencing the experience of FCR. Psychological and behavioral sequalae of FCR include frequent checking for signs and symptoms of recurrence, health care utilization, and reduced planning for the future, each of which has been demonstrated in the research literature (Custers et al., 2017; Lebel et al., 2013; Otto et al., 2018; Soriano, Valera, et al., 2018; Thewes et al., 2012). These sequalae, which can generally be categorized as hypervigilance or avoidance, temporarily reduce FCR but serve to perpetuate it over time. It is notable that none of the above-mentioned theoretical models for FCR include sleep disturbance as a correlate or consequence.

The worry, rumination, and intrusive thoughts of FCR are similar to that of generalized anxiety disorder (American Psychiatric Association et al., 2013), but focus on the possibility of cancer recurrence. There is high comorbidity between generalized anxiety disorder and sleep disturbance and this relationship has been demonstrated with both self-report and objective measures of sleep (Cox & Olatunji, 2016). The

relationship between generalized anxiety disorder and sleep disturbance should be unsurprising given the prevailing models of insomnia disorder (Harvey, 2002; Morin, 1993; Spielman, 1986), which were detailed earlier and include hyperarousal as a predisposing factor and worry, rumination and intrusive thoughts as perpetuating factors. Taken together, there is strong theoretical rationale for the relationship between FCR and sleep disturbance.

The BC trajectory is dotted with stressful events that could serve as both triggers for FCR and precipitating factors for sleep disturbance. Indeed, health problems are one of the most common precipitating factors for insomnia disorder (Bastien et al., 2004). These stressful events are not limited to diagnosis and treatment but also extend into survivorship. For example, a report on the transition from cancer diagnosis/treatment to survivorship identified challenges of this phase including emotional processing of the cancer experience, lingering treatment side effects, and reduced support from close others and medical providers (Stanton et al., 2005). FCR is a top concern reported by BC survivors during this transition (Armes et al., 2009; Stanton et al., 2005). Turning to later in survivorship, women with a history of BC, including those three to five years post-diagnosis, experience significantly more distress when undergoing mammography as compared to women without a history of BC (Gurevich et al., 2004; Porter et al., 2003). These post-treatment mammograms are also a trigger for FCR (Lee-Jones et al., 1997; McGinty et al., 2016; Soriano et al., 2019). Therefore, stressful events across the BC trajectory and associated features of

FCR, namely worry, rumination, and intrusive events, may serve as precipitating and perpetuating factors for sleep disturbance.

FCR and Sleep Disturbance: Existing Scientific Evidence

In addition to theoretical rationale, there has been a rise in published studies on the relationship between FCR and sleep disturbance (Alfano et al., 2011; Berrett-Abebe et al., 2015; Dupont et al., 2014; Flynn et al., 2010; Hall et al., 2014; Lane et al., 2019; Levesque et al., 2022; Lowery-Allison et al., 2018; Matulonis et al., 2008; Mutsaers et al., 2016; Nelson et al., 2018; Peppercorn et al., 2017; A. J. Roth et al., 2003; Strollo et al., 2020; Taylor et al., 2012). Collectively, the results of these studies support for the notion that greater FCR is related to greater sleep disturbance in survivors. Among these, five studies examined the relationship between FCR and sleep disturbance in BC survivors specifically (Alfano et al., 2011; Dupont et al., 2014; Hall et al., 2014; Lowery-Allison et al., 2018; Taylor et al., 2012). In a cross-sectional study of sleep disturbance in early-stage BC survivors, survivors who reported greater sleep disturbance also reported more FCR (Lowery-Allison et al., 2018). In two separate cross-sectional studies, intrusive thoughts about cancer and cancer-related uncertainty, both related to FCR, were positively associated with self-reported sleep disturbance in BC survivors (Hall et al., 2014; Taylor et al., 2012). In a longitudinal study across early BC survivorship, intrusive thoughts about cancer were positively associated with self-reported sleep disturbance four weeks post-treatment and 12 months later but did not predict change in self-reported sleep disturbance over

time (Dupont et al., 2014). Another longitudinal study of early BC survivorship examined whether FCR predicted self-reported sleep duration change but FCR was not predictive of change in sleep duration over time (Alfano et al., 2011).

FCR and Sleep Disturbance: Limitations of Prior Studies

While research on the relationship between FCR and sleep disturbance has grown, there are several limitations of this prior work that are important to note. Most studies were conducted with survivors of various cancer types and used cross-sectional designs. Given the increased prevalence of sleep disturbance in BC survivors relative to survivors of other cancer types, it is important to understand contributors for this growing population specifically. Cross-sectional designs reflect between-person associations – whereby individuals who report more FCR also tend to report more sleep disturbance compared to those who report less FCR. In contrast, intensive longitudinal methods, such as daily diary designs, allow for the estimation of within-person associations – comparing sleep disturbance between times when an individual reports more or less FCR than is typical for them. Compared to cross-sectional designs, intensive longitudinal designs and the within-person associations that result can control for person-level confounds and examine how processes unfold over time, thereby better informing intervention development (Bolger & Laurenceau, 2013; Hamaker, 2012; Shiffman et al., 2008).

All but one study assessed sleep via global retrospective self-report. The expert consensus recommendation for insomnia research, including in cancer survivors, is a

multi-method approach utilizing both daily self-report (e.g., sleep diaries) and objective measures (e.g., polysomnography, actigraphy) of sleep (Berger et al., 2008; Buysse et al., 2006). Such a multi-method approach is important because self-report and objective measures of sleep are not strongly correlated (Chen et al., 2015), including in BC survivors (Budhrani et al., 2015; Moore et al., 2015). Self-report of sleep is considered subjective and individuals with insomnia may especially misperceive their sleep (likely due to preoccupation with sleep disturbance and its consequences; Allison G. Harvey & Tang, 2011; Means et al., 2003). A multi-method approach is also important because subjective and objective measures of sleep have unique correlates (Lauderdale et al., 2016), including in BC survivors (Dhruva, Paul, et al., 2012).

Some of the studies assessed sleep disturbance via only one or two items. For example, in a study of the prevalence and predictors of insomnia among cancer survivors, the single item "problems falling or staying asleep" was used to categorize survivors as either having moderate to severe insomnia (those who responded "very often" or "always") or no insomnia (Peppercorn et al., 2017). As described previously, insomnia disorder can present as dissatisfaction with sleep quantity, poor sleep quality, difficulty falling asleep, *and/or* difficulty staying asleep (American Psychiatric Association et al., 2013). While related to one another (Léger et al., 2010; Sarsour et al., 2010), these sleep difficulties can exist independently (T. Roth et al., 2010; Wilkinson & Shapiro, 2012), represent different sleep problems (Buysse et al., 2006), and have unique effects on health (Dew et al., 2003). Following from this, the expert

consensus recommendation is to examine these outcomes separately (Buysse et al., 2006). Therefore, assessing only one of these parameters (e.g., assessing sleep quality only) or using single items to capture outcomes together (e.g., difficulty falling or staying asleep) is suboptimal.

Lastly, despite intimate partners' reporting both FCR and sleep disturbance and these being interdependent within-couple, we are aware of only one study that examined the relationship between FCR and sleep disturbance in partners of cancer survivors (Levesque et al., 2022). In a study of the psychosocial well-being of male family caregivers of ovarian cancer survivors (most of which were spouses/partners), greater FCR was related to greater subjective sleep disturbance. We are aware of no published studies examining FCR-sleep disturbance links in the partners of BC survivors specifically or within-couple. While there are no published studies, we have explored these associations in our own work (Perndorfer, Soriano, Siegel, Spencer, Otto, et al., 2022). Specifically, we examined the relationship between FCR and subjective sleep disturbance in early-stage BC survivors and their partners in two distinct and important periods in early survivorship—the conclusion of adjuvant treatment and the first post-treatment mammogram. These periods reflect unique transitions in the first year of survivorship. FCR is a top concern reported by BC survivors during the transition from diagnosis/treatment to survivorship (Armes et al., 2009; Stanton et al., 2005). As previously described, additional challenges of this phase include emotionally processing the cancer experience, coping with ongoing treatment side effects, and loss of support (Stanton et al., 2005). The first, post-

treatment mammogram (approximately 12 months post-diagnosis) is a looming threat for BC survivors (Gurevich et al., 2004; Porter et al., 2003) and a trigger for FCR (Lee-Jones et al., 1997; McGinty et al., 2016; Soriano et al., 2019). In each time period, FCR was assessed once via three, validated self-report measures. Sleep, including sleep duration, sleep quality, difficulty falling asleep, and difficulty staying asleep, was assessed daily for 21 consecutive days via sleep diaries. Associations were examined between a latent FCR factor and the daily, subjective sleep outcomes averaged across each 21-day diary period. By assessing FCR and sleep disturbance in both survivors and partners, we were able to examine these relationships from a dyadic perspective, including both actor and cross-partner effects (Kenny et al., 2006). Actor effects refer to the relationship between one's own FCR and one's own sleep disturbance while cross-partner effects refer to the relationship between one's own FCR and one's partner's sleep disturbance.

The results of our study support greater FCR being related to greater sleep disturbance among couples coping with early-stage BC. That is, findings revealed actor and cross-partner associations between a global FCR factor and daily, subjective sleep disturbance (averaged across each time period) for both survivors and partners in the expected direction. Across both time periods, the actor and cross-partner effects differed somewhat between survivors and partners. Also, the results for the specific sleep difficulties (sleep duration, sleep quality, difficulty falling asleep, and difficulty staying asleep) differed between the two periods, with FCR being most consistently related to sleep quality. Therefore, relationships between FCR and sleep disturbance

may depend on one's status as a survivor or partner, vary per sleep difficulty, and change across the survivorship trajectory.

It is important for us to note that the original goal for our research on FCR and subjective sleep disturbance in couples coping with early-stage BC (described above) was to examine the daily, within-person associations between FCR and subjective sleep disturbance. It follows from this, that in addition to daily, subjective sleep disturbance, we also assessed FCR at the daily level. However, in both time periods, we did not find significant or sizeable within-person associations for either survivors or partners (actor or cross-partner effects). The overarching purpose of the present study was to examine these daily, within-person associations with daily FCR, but instead using daily *objective* sleep disturbance. As discussed previously, self-report and objective measures of sleep are not strongly correlated and have unique correlates, including in BC survivors (Dhruva, Paul, et al., 2012). Therefore, it remains possible that daily FCR is related to daily, objective sleep disturbance at the within-person level.

Chapter 2

THE PRESENT STUDY

The primary goal of the present study was to examine the daily, within-person associations between FCR and objectively measured sleep disturbance in early-stage BC survivors and their partners. These relationships were examined in two distinct and important time periods in early survivorship: (1) the period after survivors completed adjuvant treatment and (2) the period spanning survivors' first, post-treatment mammogram (See Figure 1 *Study Timeline*). Detailed earlier, these periods reflect unique transitions in early survivorship and it is therefore plausible that relationships between FCR and objective sleep disturbance differ between them. Each period consisted of 21 consecutive days of data collection: daily self-report of FCR and continuous collection of physical activity and sleep via actigraphy. Daily FCR and daily objective sleep disturbance were assessed in both survivors and partners, allowing us to examine these relationships from a dyadic perspective. Specifically, we examined the relationship between one's own FCR and one's own sleep disturbance (actor effects) and the relationship between one's own FCR and one's partner's sleep disturbance (cross-partner effects; Kenny et al., 2006). See Figure 2 *Actor Partner Interdependence Modeling (APIM) of FCR and Objective Sleep Disturbance.*

Following published recommendations for studies using actigraphy to assess sleep in adults with cancer (Berger et al., 2008), the specific sleep difficulties we examined were sleep period, total sleep time, awakenings, wake after sleep onset, and sleep efficiency. Sleep period refers to the number of minutes between sleep onset and sleep

offset whereas total sleep time refers to the number of minutes scored as "asleep" between sleep onset and offset (ActiGraph, 2012; Fekedulegn et al., 2020). Awakenings refers to the number of unique awakenings between sleep onset and sleep offset whereas wake after sleep onset refers to the number of minutes scored as "awake" between sleep onset and sleep offset (ActiGraph, 2012). Sleep efficiency, a percentage, is the quotient of the total sleep time divided by the sleep period length. These sleep outcomes are also defined in Supplemental Appendix S1 *Objective Sleep Disturbance Outcomes* and described in detail in the Method.

Aim 1: Describe Objective Sleep Disturbance in BC Survivors and Their Partners after Adjuvant Treatment and at the First, Post-Treatment Mammogram

A review of objective measures of sleep disturbance in BC survivors described a paucity of research on sleep disturbance in the post-treatment period and called for future research with actigraphy measurement of at least seven nights (Budhrani et al., 2015). Few studies have assessed objective sleep disturbance among partners of cancer survivors (cf. Carney et al., 2011; Dhruva, Lee, et al., 2012) and none among these have examined objective sleep disturbance in partners of BC survivors specifically. We aimed to address these gaps by describing sleep disturbance, measured via actigraphy for 21 consecutive days, in BC survivors and their partners for two distinct post-treatment periods—after survivors' completion of adjuvant treatment and spanning survivors' first, post-treatment mammogram.

Current Sample Rates vs. Comparison Sample Rates

We compared objective sleep disturbance among BC survivors and their partners with rates from a study sample most comparable to that of the current study. Few studies have assessed sleep via actigraphy in a nationally representative sample (cf. Kurina et al., 2015; Lauderdale et al., 2006). Among these, is an ancillary to the Coronary Artery Risk Development in Young Adults (CARDIA) study (Lauderdale et al., 2006). The CARDIA study is a multi-site, prospective study of cardiovascular risk factors in a nationally representative study (Friedman et al., 1988). The ancillary study examined objective sleep, measured via actigraphy over three nights, in 699 participants of early- and middle-age at one of the four CARDIA study sites. The sample included 198 White women with a mean age of 44 (*SD* = 3) and modal family income ≥$100,000. The sample also included 177 White men with a mean age of 44 (*SD* = 3) and modal family income of ≥$100,000. Of the few studies to examine objective sleep disturbance in a nationally representative sample, this ancillary study samples a study population and contains measures most comparable to those of the current study. The characteristics for the current sample are detailed in the Method. Briefly, the average age for survivors was 57 (*SD* = 9) and the average age for partners was 59 (*SD* = 10). Most survivors (87%) and partners (84%) identified as Non-Hispanic/Latino White and the modal family income was >$100,000.

For White women in the ancillary study, the mean total sleep time was 6.71 hours (*SD* = 0.89) and the mean sleep efficiency was 85.7% (*SD* = 6.1). The study did not report on sleep period length, number of awakenings, or wake after sleep onset.

The study did report on time in bed, which is a nuanced but important distinction from sleep period that will be described further in the Method as well as Discussion. Prior research suggests that BC survivors experience more sleep disturbance, assessed via self-report and objective measures, as compared to the general population as well as healthy, age-matched controls and that this sleep disturbance persists across survivorship (Budhrani et al., 2015; Otte et al., 2010; J. Savard et al., 2009, 2011). Therefore, we hypothesized that BC survivors would demonstrate significantly less total sleep time and poorer sleep efficiency as compared to these population rates and that this will be true for both periods. For White men in the ancillary study, the means for the sleep disturbance outcomes were as follows: total sleep time = 6.09 hours (*SD* = 1.13); sleep efficiency = 82.4% (*SD* = 9.12). Although under-researched, there is evidence to suggest that partners of BC survivors also experience elevated levels of sleep disturbance (Carney et al., 2011; Chang et al., 2007; Dhruva, Lee, et al., 2012). Following from this, we hypothesized that partners would also demonstrate significantly less total sleep time and poorer sleep efficiency as compared to these population rates in both periods.

Sample Rates vs. Recommendations

We also compared the objective sleep disturbance of couples coping with BC to published recommendations for sleep duration and quality. The National Sleep Foundation recommends that adults sleep at least 7 hours per night (National Sleep Foundation, 2020). Given reports of elevated sleep disturbance in BC survivors and

partners, we hypothesized that both survivors and their partners would sleep significantly less than this recommended 7 hours in both periods. The National Sleep Foundation also published expert consensus recommendations for indicators of good sleep quality across the lifespan (Ohayon et al., 2017). For adults, ≤ 1 awakening, ≤ 20 minutes of wake after sleep onset, and sleep efficiency ≥ 85% are considered to be indicative of good sleep quality. Again, given evidence for elevated sleep disturbance among both BC survivors and their partners, we hypothesized that survivors and partners would experience significantly more awakenings, greater wake after sleep onset, and poorer sleep efficiency when compared with these indices.

Survivors vs. Partners

We also examined the relationship between survivors' objective sleep disturbance and partners' objective sleep disturbance, separately for both periods. Prior research with objective measures of sleep suggests that sleep is concordant within couples, including in couples coping with cancer (Carney et al., 2011; Gunn et al., 2015; Lee et al., 2018; Meadows et al., 2009). Following from this, we hypothesized that survivors' and partners' sleep difficulties would be significantly and positively related in both periods – at the between- and within-person level. Few studies have tested mean differences between the objective sleep disturbance of cancer survivors and their partners (cf., Carney et al., 2011). Therefore, we considered comparing the mean levels of objective sleep disturbance of survivors to those of partners exploratory.

Before vs. After Mammogram

To further describe sleep in the period spanning survivors' first, post-treatment mammogram, we compared participants' objective sleep disturbance before the mammogram with their own objective sleep disturbance after the mammogram. The first, post-treatment mammogram can be conceptualized as an impending threat (Gurevich et al., 2004; Lee-Jones et al., 1997; McGinty et al., 2016; Porter et al., 2003; Soriano et al., 2019) and in the present study, all but one couple received negative mammography results on the same day as their appointment. We therefore predicted that survivors' and partners' mean levels of objective sleep disturbance would be significantly poorer before versus after the mammogram.

Diary Period 1 vs. Diary Period 2

Moreover, we compared survivors' and partners' objective sleep disturbance in the period after adjuvant treatment with their own sleep in the period spanning the first, post-treatment mammogram. Given the lack of research on objective sleep disturbance in the post- treatment period, particularly with BC survivors and partners, we considered comparing the mean levels of objective sleep disturbance between the two time periods exploratory.

Aim 2: Examine Between-Person Associations between FCR and Objective Sleep Disturbance

The purpose of aim 2 was to examine the relationship between FCR and objective sleep disturbance at the between-person level, separately for each of the two

time periods. We hypothesized that FCR would be positively related to objective sleep disturbance and that this effect would be above and beyond daytime total sleep time (i.e., time spent napping). Specifically, we hypothesized that BC survivors and partners who reported more daily FCR on average, would also exhibit more objective sleep disturbance on average, after controlling for their own average levels of daytime sleep. Results from our own work suggest actor and cross-partner effects for FCR and subjective sleep disturbance at the between-person level (Perndorfer et al., 2022). Following from this, we also hypothesized that survivors who reported more FCR on average would have partners with more objective sleep disturbance on average, after controlling for partner's average level of daytime sleep (and vice versa with partners' FCR and survivors' sleep). See Figure 2 for a depiction of these actor- and cross-partner effects. We did not make specific hypotheses for each of the sleep parameters. Given the lack of research on FCR and objective sleep, we were interested not only *if* sleep is disturbed, but also in what ways. Also, as stated earlier, these outcomes represent unique sleep problems (Buysse et al., 2006), and have unique relationships with health (Dew et al., 2003) and it is therefore recommended to examine them independently (Buysse et al., 2006). While we did not make separate hypotheses for the sleep outcomes, we operationalized greater sleep disturbance as shorter sleep period, less total sleep time, more awakenings, greater wake after sleep onset, and poorer sleep efficiency.

Aim 3: Examine Daily, Within-Person and Within-Couple Associations between Fear of Cancer Recurrence and Objective Sleep Disturbance

The focal aim, Aim 3, examined the relationship between FCR and objective sleep disturbance at the daily, within-person and within-couple level. It is important to note that these within-person associations can differ in size and direction from the corresponding between-person associations of Aim 2. Similar to Aim 2, these relationships were examined separately for each of the two time periods in early survivorship. We hypothesized that FCR would be related to objective sleep disturbance through both actor and cross-partner effects – see Figure 2. Regarding actor effects, we hypothesized that on a day that survivors and partners reported more FCR than is typical for them, they would also exhibit more objective sleep disturbance that night, after controlling for any daytime sleep from that same day. Regarding cross-partner effects, we hypothesized that on a day that survivors reported more FCR than is typical for them, their partners would exhibit more objective sleep disturbance that night, after controlling for partner's daytime sleep that same day (and vice versa for partners' FCR and survivors' sleep disturbance). Again, we did not make specific hypotheses for each of the sleep outcomes but operationalized greater sleep disturbance as shorter sleep period, less total sleep time, more awakenings, greater wake after sleep onset, and poorer sleep efficiency.

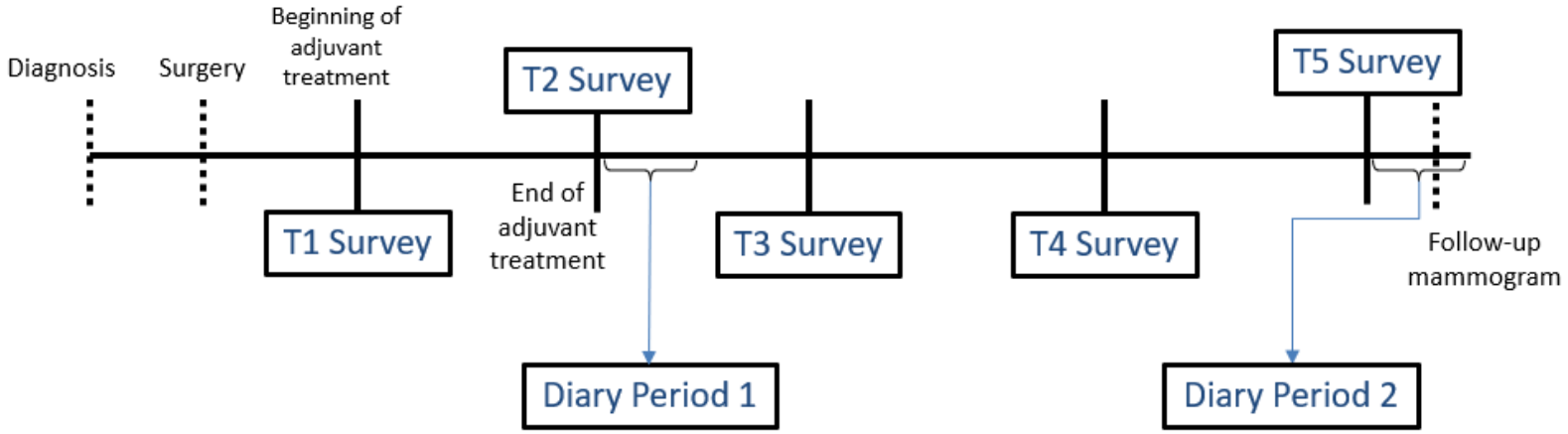


Figure 1 Study timeline of the intensive longitudinal parent study. The present study consists of secondary analyses of the two diary periods: (Diary Period 1) the period after survivors completed adjuvant treatment and (Diary Period 2) the period spanning survivors' first, post-treatment mammogram. Each of the daily diary periods consisted of 21 consecutive days during which participants reported FCR each evening and wore an actigraphy device to measure continuous physical activity and sleeps

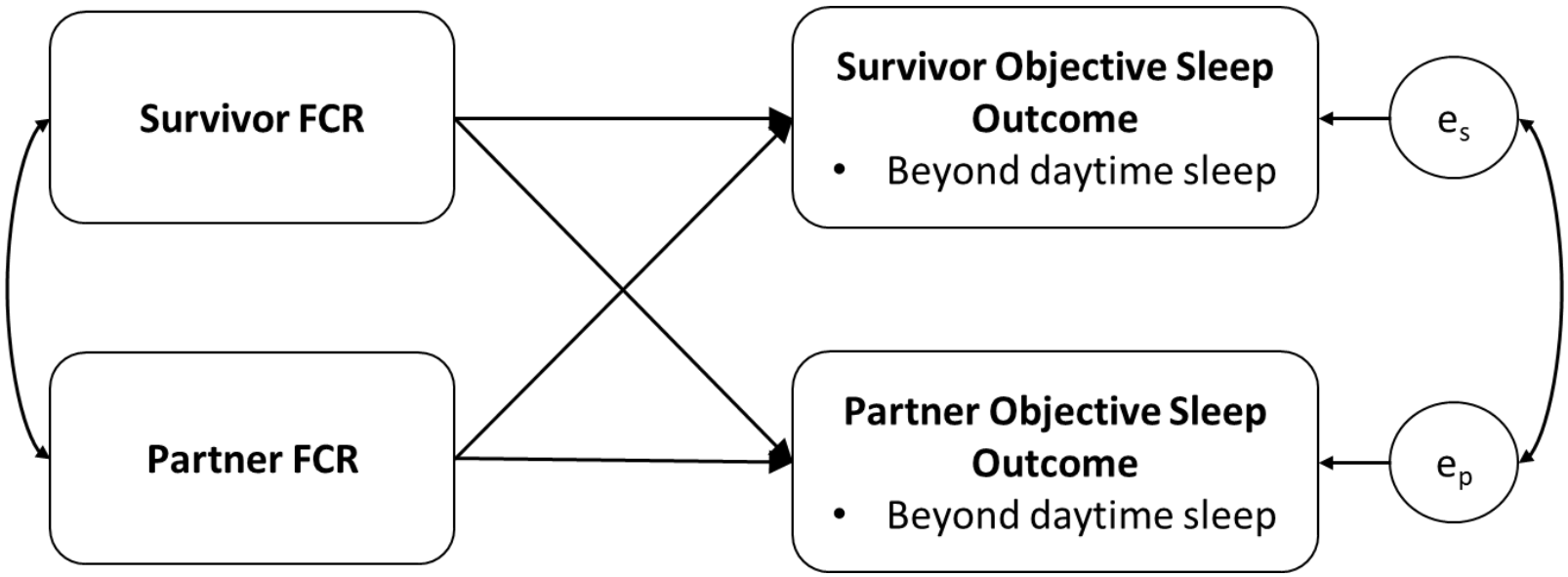


Figure 2 Actor partner interdependence modeling (APIM) of FCR and objective sleep disturbance. Actor effects refer to the associations between one's own FCR and own's own objective sleep disturbance (Kenny et al., 2006). Cross-partner effects refer to the associations between one's own FCR and one's partner's objective sleep disturbance. APIM was conducted at both the between- and within-person level. Actor and cross-partner effects were estimated simultaneously in each model.

Chapter 3

METHOD

Participants

The current study consists of secondary analyses of an intensive longitudinal study, *Surviving Cancer Together*. The parent study was approved by both the University of Delaware and Christiana Care Health System Institutional Review Boards (FWA00006557; CCC# 33026) and its purpose was to examine the relationship between interpersonal patterns of disclosure (e.g., social constraints, protective buffering) and FCR among early-stage BC survivors and their partners (Perndorfer et al., 2019; Soriano et al., 2019, 2021; Soriano, Pasipanodya, et al., 2018; Soriano, Perndorfer, et al., 2018). Following from this, the parent study was not specifically designed nor powered for the aims of the current study and these aims are the first to use the objective sleep disturbance data.

To participate in the parent study, female BC survivors had to: (1) be diagnosed with stage 0-IIIA BC; (2) have received BC surgery; (3) have spouses or long-term partners willing to participate; (4) have no prior cancer diagnoses; (5) speak English; and (6) live within an hour of the study site. See Figure 3 *Participant Flow for Parent Study, Surviving Cancer Together*. Potential eligibility was assessed via electronic medical record review, which resulted in 463 survivors being contacted. Of

the 463 survivors contacted, 154 actively declined participation, 116 passively declined, and 110 were determined to be ineligible. The most common reasons for actively declining were not having enough time to participate and the partner being unwilling to participate. The most common reason for ineligibility was being unpartnered. Seventy-nine couples provided written informed consent and participated in the parent study.

The current aims focused on two time periods of the parent study: the period shortly after survivors completed adjuvant treatment (hereafter referred to as diary period 1; DP1) and the period spanning survivors' first, post-treatment mammogram (hereafter referred to as diary period 2; DP2). Seventy-two and 57 couples provided data for DP1 and DP2, respectively. That 15 fewer couples provided data for DP2 is due to seven couples withdrawing between the time periods, five having a scheduling conflict with DP2, and another three couples declining to participate in DP2. We previously demonstrated that couples who provided data for both diary periods did not significantly differ from those who only provided data for DP1 with respect to age, relationship length, income, survivor BC stage, and survivor adjuvant treatment type (Perndorfer et al., 2022).

While 72 and 57 couples provided data for DP1 and DP2, respectively, the current aims are the first to use the actigraphy data. For DP1, valid actigraphy data were available for 67 survivors (93%) and 64 (89%) spouses. Among survivors, three were excluded due to being shift workers, one did not wear the accelerometer, one actigraphy data file was missing, and one survivors' data was not compatible with the

actigraphy processing methods (n = 5). Among partners (n = 8), two were excluded due to being shift workers, one was excluded due to using a wheelchair, three actigraphy data files were missing, and one actigraphy data file was mislabeled with the incorrect ID number and could there not be identified. For DP2, valid actigraphy data were available for 50 survivors (88%) and 48 (84%) spouses. For DP2, three survivors were excluded due to being shift workers, three did not wear the accelerometer, and one actigraphy data file was missing (n = 7). Among partners, one was excluded due to being a shift worker, one was excluded due to using a wheelchair, five did not wear the accelerometer, one had too much non-wear time for valid sleep detection, and one had technical difficulties with the accelerometer (n = 9). Shift workers were excluded because the parent study did not provide clear or consistent instructions for shift workers about when to complete their morning and evening diaries in relation to their shift work and sleep schedule. While there is some evidence for the validity of wrist actigraphy in individuals who use wheelchairs, validity may depend on clinical characteristics (e.g., location of spinal cord lesion; Spivak et al., 2007). Such clinical characteristics were not assessed for the partner who uses a wheelchair and so this partner's data were excluded from analyses.

For survivors who provided data for DP1 of the current study (N = 67), the mean age was 58 (SD = 9). For partners who provided data for DP1 of the current study, (N = 64), the mean age was 60 (SD = 10). Most (94%) couples were married – for an average of 29 years (SD =14). Most (97%) couples were heterosexual (i.e., all but two partners were male). Most identified as Non-Hispanic/Latino White (88% of

survivors and 84% of partners). Ten percent of survivors identified as Black and 2% identified as Asian. Thirteen percent of partners identified as Black and 3% identified as Asian. Forty-nine percent of survivors were diagnosed with Stage I BC followed in order of percentage by Stage II (34%), Stage 0 (DCIS/LCIS; 15%), and Stage IIIA (2%). Seventy percent of survivors underwent radiation and 33% underwent chemotherapy. Eighty percent of survivors were prescribed adjuvant hormone therapy.

Procedure

Participation in the parent study began shortly after survivors' BC surgery and concluded shortly after their first, post-treatment mammogram. The post-treatment mammogram occurred an average of 12.2 months (*SD* = 1.9) after survivors' initial BC diagnosis. As stated throughout, the current study focused on the time period shortly after survivors completed adjuvant treatment and the time period spanning their post-treatment mammogram. At both periods, both survivors and partners completed a cross-sectional survey, which was followed approximately two weeks later by a 21-day daily diary period. Both the cross-sectional surveys and daily diaries were completed online. Survivors and partners were emailed separate links and asked to complete all items independently. On each of the 21 diary days, participants were asked to complete two brief surveys–within an hour of waking up and going to sleep. The evening diary included measures of daily FCR. During both DP1 and DP2, participants wore an accelerometer to continuously measure physical activity and sleep. In DP1, the diary completion rates for survivors and partners was 87% and 84%,

respectively. In DP2, the diary completion rate for survivors was 91% and the diary completion rate for partners was 89%. For DP1, on average, actigraphy data were available for 19.91 (95%) of diary days for survivors and for 19.56 (93%) of diary days for partners. For DP2, on average, actigraphy data were available for 19.48 (93%) of diary days for survivors and 20.29 (97%) for partners.

For DP1, the cross-sectional survey was completed an average of 6.2 months (*SD* = 2.3) post-diagnosis, which was also an average of 20.2 days (*SD* = 30.4) post-treatment. The daily diaries for DP1 began an average of 21.2 days (*SD* = 14.5) following the cross-sectional survey. For DP2, the cross-sectional survey was completed an average of 11.8 months (*SD* = 1.9) post-diagnosis, which was also an average of 6.2 months (*SD* = 2.4) post-treatment. The daily diaries for DP2 began an average of 8 days (*SD* = 6.8) following the cross-sectional survey, which was an average of 13 days (*SD* = 5.6) before the mammogram. All but one survivor received negative mammography results on the same day as the appointment.

Measures

Fear of Cancer Recurrence

Daily FCR was measured in the evening diaries. At the time of the parent study, there were no peer-reviewed measures for daily FCR. Thus, the daily FCR items were adapted from the well-validated, Fear of Cancer Recurrence Inventory - Severity, Distress, and Insight subscales (Simard & Savard, 2009). This daily FCR measure has been used in prior reports of this study sample (see Perndorfer et al.,

2019; Soriano et al., 2019; Soriano, Perndorfer, et al., 2018; Soriano, Valera, et al., 2018). For specific wording of the items, see Supplemental Appendix S2 *Daily Items for FCR*. Survivors reported fear about the possibility of their own BC recurring while partners reported their fear related to the possibility of the survivor's BC recurring. The first item assessed severity of FCR, which was operationalized as how much time participants spent thinking about FCR that day. The five remaining items assessed emotions (i.e., anxiety, sadness, anger, helplessness, and worry) related to FCR. For example, "*I was sad, discouraged, or disappointed about the possibility of cancer recurrence*." All six items used Likert-type response scales wherein greater responses indicated greater FCR. Responses were summed (possible range 0-24) with acceptable within-person reliability for both DP1 (patients' ω= 0.89; spouses ω' = 0.88) and DP2 (patients ω' = 0.90; spouses ω' = 0.90).

Objective Sleep Disturbance

Daily objective sleep disturbance was measured using actigraphy. In study visits, study staff fitted participants with triaxial ActiGraph GT3X monitors (ActiGraph LLC, Pensacola, FL, USA) on their non-dominant wrists. Participants were instructed on the use of the accelerometers and asked to wear them, starting from the study visit, for 24-hours per day for 21 consecutive days and nights overlapping DP1 and DP2. It follows from this that sleep was measured on both weekdays and weekends. DP1 and DP2 were scheduled according to each survivors' BC trajectory. For example, DP2 was scheduled to start approximately two weeks before and

conclude approximately one week after each survivor's first, post-treatment mammogram. Therefore, the number of weekdays vs. weekend days included in each 21-day period differs slightly between couples. Most participants were fitted with a non-removable wrist strap. However, some participants were either fitted with or provided a removable strap for reasons including air travel, not being able to wear an accelerometer at work, scheduled medical procedures, not being able to wear an accelerometer in recreational activities (e.g., karate, swimming), and participant preference. For DP1, three survivors (~4%) and eight partners (~13%) were either fitted with or provided a removable strap. For DP2, 4 survivors (8%) and five partners (~10%) were fitted with or provided a removable strap. The GT3X accelerometer is a waterproof, watch-looking device (dimensions 4.6 x 3.3 x 1.5 cm) that records continuous physical activity and sleep-wake data. The accelerometers were initialized with a sampling rate of 30 Hz, resulting in a battery life expectancy of 31 days.

Actigraphy Data Processing

The manufacturer's ActiLife software (v6.13.4; ActiGraph, 2019) was used to download and process the data, which were accumulated into 60-second epochs. The processing methods used in the current study are consistent with the ActiLife 6 User's Manual (ActiGraph, 2012), prior research using the ActiGraph monitors and ActiLife software for detecting sleep in adult populations, including BC survivors (Kreutz et al., 2021; Myllyntausta et al., 2020; Wennman et al., 2019), as well as published recommendations on the use of actigraphy for measuring sleep, including in adults

with cancer (Berger et al., 2008; Fekedulegn et al., 2020). ActiLife's Sleep Analysis tool was used to detect sleep periods, visualize the data, and hand-edit the sleep periods. First, the Cole-Kripke algorithm was applied to the data (Cole et al., 1992; ActiGraph, 2020). The Cole-Kripke algorithm has been validated for wrist-worn actigraphy with adult populations and classifies each 60-second epoch as either being "asleep" or "awake". To implement the Cole-Kripke algorithm, the ActiLife software first adjusts the epoch data to be consistent with the validation paper by 1) dividing the counts of the y-axis by 100 and 2) setting any of these scaled values that are >300 to 300 (ActiGraph, 2018). Then, each 60-second epoch is classified as asleep or awake based on a seven-minute window consisting of the four epochs before and the two epochs after the epoch in question. The following algorithm is applied to this seven-minute window: .001 * (106 * Epochx-4 + 54 *Epochx-3 + 58 * Epochx-2 + 76 * Epochx-1 + 230 * Epochx+ 74 * Epochx+1+ 67 * Epochx+2). Epochs for which the result of this algorithm is <1 are classified as asleep whereas epochs for which the result is ≥1 are classified as awake.

Next, the Detect Sleep Periods feature was used to apply the modified Tudor-Locke algorithm to these 60-second asleep and awake epochs to identify sleep periods (Tudor-Locke et al., 2014; ActiGraph, 2020). The Tudor-Locke algorithm defines the beginning of a sleep period (sleep onset) as the first five consecutive minutes classified as asleep. The end of a sleep period (sleep offset) is defined as the first ten consecutive minutes classified as awake after sleep onset. For the Tudor-Locke algorithm, the minimum amount of time required between sleep onset and offset is

160 minutes and the maximum sleep period length is 1,440 minutes. Therefore, the possible range for sleep period (and thereby TST and WASO) was 160-1440 minutes. The Detect Sleep Periods feature is designed to ignore non-wear periods – i.e., periods when the device was removed from the wrist (ActiGraph, 2012).

After the sleep periods were detected, they were visually inspected and hand-edited by the same person (this author) to 1) delete any periods before the measurement period that were scored as sleep, 2) delete any non-wear times that were scored as sleep, and 3) combine sleep periods occurring the same night that were scored as two or more separate sleep periods. These edits are consistent with prior research using the ActiGraph monitors and ActiLife software for measuring sleep in adult populations (e.g., Myllyntausta et al., 2020; Wennman et al., 2019), are described in detail below, and are depicted in Supplemental Appendix S3.

Despite the Detect Sleep Periods feature being designed to ignore non-wear periods (ActiGraph, 2012), there were instances in which it was evident that the period between the initialization of the accelerometer and the fitting of the accelerometer to the participant's wrist was scored as sleep. In these instances, the sleep period was deleted.

As previously noted, most participants were fitted with a nonremovable wrist strap and asked to wear the accelerometer for 24-hours per day for 21 consecutive days and nights in both DP1 and DP2. Participants who were fitted with or provided a removable strap (n = 20 across both DP1 and DP2) were asked to record non-wear times and report these times to study staff. For participants who were fitted with or

provided a removable strap, the sleep periods were visualized and compared to their recorded non-wear times and any recorded non-wear times scored as sleep were deleted. For all participants, including those fitted with a non-removable strap, the sleep periods were visualized to identify any potentially unrecorded/unreported non-wear times. Non-wear times are evident when there is a period of high activity counts abruptly followed by a period of zero counts, which is then abruptly followed by another period of high activity counts (Myllyntausta et al., 2020). Any non-wear times scored as sleep were deleted.

Multiple sleep periods can be detected in one day (or 24-hour period) and there were instances in which, due to awakenings, sleep occurring the same night was scored as two or more separate sleep periods. For actigraphy among adults with cancer, it is recommended that accelerometers have event markers and/or be coupled with daily sleep diaries that assess the time one *intends* to go to sleep (also known as in bed time or lights out) and the time one arose (also known as get up time; Berger et al., 2008). Elaborated on in the Discussion, the sleep diaries used in the current study did not assess in bed time or get up time. Additionally, the accelerometers did not have event markers. In bed time is distinct from sleep onset due to the time it takes to fall asleep. Get up time is distinct from sleep offset due to the possibility of lingering in bed after waking. In the absence of in bed time and get up time, the diary completion times were used to set day and night intervals. Specifically, if a 24-hour period contained more than one sleep period, these periods were compared to the diary completion times for that participant on that date. As stated previously, participants

were instructed to complete the evening diary within an hour of going to sleep and the morning diary within an hour of waking up. If two or more sleep periods occurred within this window, they were combined and coded as the night sleep period and the sleep parameters used were from this combined sleep period. Sleep periods occurring outside of this window (i.e., between the morning diary and evening diary) were coded as daytime sleep episodes (i.e., naps). In the absence of data for in bed time and get up time, apart from these three edits, sleep onset and sleep offset as determined by the algorithms were not edited.

See Supplemental Appendix S1 *Objective Sleep Disturbance Outcomes.*

Consistent with published recommendations for actigraphy among adults with cancer, the five sleep parameters used in the current study were 1) were sleep period (the time between sleep onset and sleep offset), 2) total sleep time (TST; the time spent asleep between sleep onset and offset), 3) awakenings (the number of unique awakenings between sleep onset and offset), wake after sleep onset (WASO; the minutes spent awake between sleep onset and offset), and sleep efficiency (SE; the quotient of total sleep time divided by sleep period length).

Data Analytic Plan

Aim 1: Describe Objective Sleep Disturbance in BC Survivors and their Partners after Adjuvant Treatment and at the First, Post-Treatment Mammogram

All t-tests (summary independent samples, one-sample, paired samples) conducted for Aim 1 were conducted in IBM SPSS Statistics (Version 28).

Sample Rates vs. Comparison Sample Rates

First, mean levels of TST and SE were compared to the comparison sample rates published by Lauderdale and colleagues (2006), which were detailed earlier. Specifically, summary independent samples t-tests were performed to test whether the means for TST and SE for survivors and partners in DP1 and DP2 were significantly different from these comparison sample rates. The summary independent samples t-tests considers the number of cases for both samples as well as the means and *SD*s for both samples.

Sample Rates vs. Recommendations

Second, the means for TST, awakenings, WASO, and SE were compared to published recommendations for sleep quantity and quality in adults, which were also detailed earlier (National Sleep Foundation, 2020; Ohayon et al., 2017). One-sample t-tests were performed to test whether the means for TST, awakenings, WASO, and SE for survivors and partners in DP1 and DP2 significantly differed from these recommendations, which were the test values.

Survivors vs. Partners

Third, the mean levels of objective sleep disturbance for survivors were compared to those of partners and these comparisons were done separately in DP1 and DP2 (e.g., survivors' mean TST in DP1 with partners' mean TST in DP1, and so on…). Bivariate correlations, including between- and within-person correlations, between survivors' and partners' means for the five daily objective sleep disturbance

outcomes were performed in Mplus (Version 8; Muthén & Muthén, 1998-2017), separately for DP1 and DP2. Then, paired samples t-tests were used to test for mean differences between survivors' and partners' outcomes, separately in DP1 and DP2.

Before vs. After Mammogram

Fourth, participants' mean levels of objective sleep disturbance before the mammogram were compared with their own mean levels after the mammogram (e.g., survivors' mean TST before the mammogram vs. survivors' mean TST after the mammogram). Paired samples t-tests examined mean differences between participants' outcomes before versus after the mammogram.

Diary Period 1 vs. Diary Period 2

Fifth and finally, survivors' mean levels of objective sleep disturbance were compared between DP1 and DP2 (e.g., survivors' mean TST in DP1 with survivors' mean TST in DP2, and so on…) and the same was done for partners. Paired samples t-tests were used to test mean differences between participants' outcomes at DP1 versus DP2.

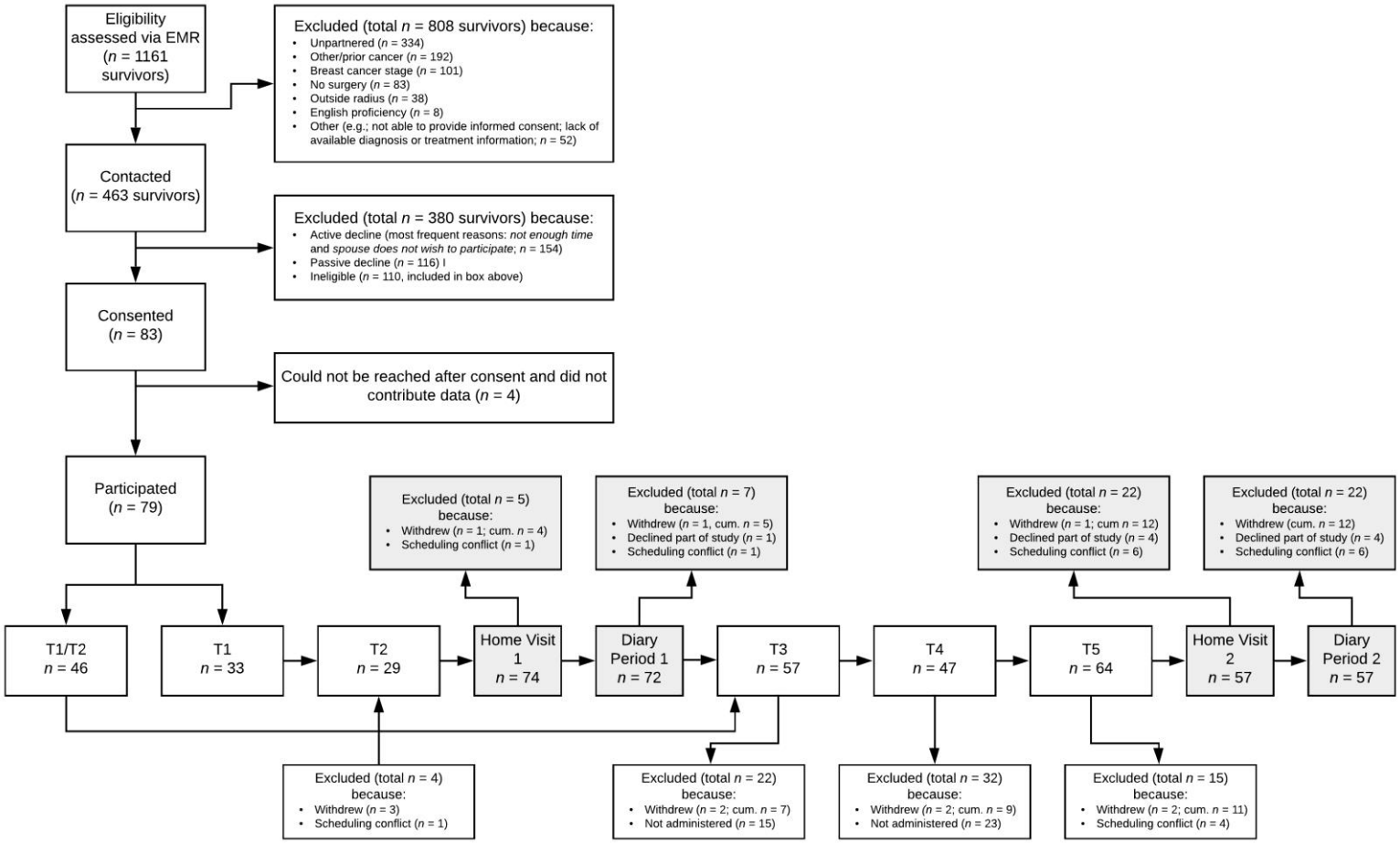
Aim 2 and Aim 3: Examine Between-Person and Daily, Within-Person Associations Between FCR and Objective Sleep Disturbance

Multilevel dyadic path modeling was used to examine both the between and daily, within-person associations between FCR and objective sleep disturbance. This multilevel dyadic path modeling approach, which accommodates the nested structure

of the daily diary data (partners nested in couples and repeated daily diary data crossed by participants; Bolger & Laurenceau, 2013), was conducted in Mplus (Version 8; Muthén & Muthén, 1998-2017). In all models, time was entered as a fixed, within-person covariate to control for any linear effect of time across each of the two diary periods. For all effects, we estimated the random intercept and random slopes to allow for person-to-person variability in the intercepts for the objective sleep disturbance outcomes as well as in the slopes for the effects. To obtain between- versus within-person associations between FCR and sleep outcomes, Mplus (Version 8; Muthén & Muthén, 1998-2017) conducted a latent separation of the FCR predictors and sleep outcomes. This latent separation results in a measure of FCR that contains only between-person variability and is used as a person-level predictor of the random intercepts for the sleep outcomes. In this context, between-person variability reflects mean levels of variable. Moreover, latent separation results in a measure of FCR that contains only within-person variability and is used as a predictor of measures of sleep outcomes containing only within-person variability. Because of the need to estimate several random slope effects, Bayesian estimation with noninformative priors was used, which essentially results in maximum likelihood estimates. Bayesian estimation in Mplus (Version 8; Muthén & Muthén, 1998-2017) assumes that missing data are missing at random – an assumption that missingness is a function of covariates or outcomes in the model.

Both between- and within-person associations were examined from a dyadic perspective. Specifically, we used actor-partner interdependence modeling (APIM;

Kenny et al., 2006) to estimate actor and cross-partner effects simultaneously in each model – see Figure 2. For between-person associations, survivors' mean sleep disturbance was regressed on both their own as well as their partner's mean level of FCR, controlling for survivors' mean level of daytime sleep duration. Partners' mean level of sleep disturbance was regressed on both their own as well as survivor's mean level of FCR, controlling for partners' mean level of daytime sleep duration. For daily, within-person associations, survivors' daily within-person objective sleep disturbance was regressed on both their own as well as their partner's within-person FCR reported in the evening, controlling for survivors' daytime sleep duration that same day. Partners' within-person daily objective sleep disturbance was regressed on their own as well as the survivors' FCR reported in the evening, controlling for partner's daytime sleep duration that same day. Estimation of multilevel APIM effects requires rows of data in which *both* the survivors' and partners' predictors (i.e., FCR) are observed. While actor and cross-partner effects were estimated simultaneously in each model, separate models were estimated for each of the five objective sleep disturbance outcomes (sleep period, TST, awakenings, WASO, & SE).



Note: EMR = electronic medical record. Unless otherwise specified, numbers reported here reflect numbers of *couples* (not individuals). Due to the timing of survivors' treatment and follow-up mammograms, the larger longitudinal project utilized a flexible temporal design. As part of this design, T1 and T2 were combined for some couples and some couples were excluded at T3 and T4 intentionally (the questionnaire was "not administered"). The present study focuses on Diary Period 1 and 2, during which FCR was reported daily and objective sleep disturbance was assessed via actigraphy.

Figure 3 Participant Flow for Parent Study, *Surviving Cancer Together*.

Chapter 4

RESULTS

Aim 1: Describe Objective Sleep Disturbance in BC Survivors and Their Partners after Adjuvant Treatment and at the First, Post-Treatment Mammogram

Diary Period 1 (Completion of Adjuvant Treatment)

See Tables 1 and 2 for bivariate correlations and descriptive statistics for key variables from DP1. In DP1, daytime sleep periods, or naps, were detected for only 4% of the total days for survivors and only 3% of the total days for partners. The mean length of these naps was 211.38 minutes (*SD* = 99.76) for survivors and 209.79 minutes (*SD* = 99.02) for partners. In DP2, naps were detected on only 4% and 5% of the total days for survivors and partners, respectively. The mean length of survivors' naps was 191.58 minutes (*SD* = 63.19) and the mean length for partners' naps was 172.18 minutes (*SD* = 52.16). It is worth noting again here that the Tudor-Locke algorithm (Tudor-Locke et al., 2014) used to detect sleep periods uses a minimum sleep period length of 160 minutes and so naps for which the sleep period length < 160 minutes were not detected. These actigraphy data processing methods are consistent with prior research, including in BC survivors (Kreutz et al., 2021; Myllyntausta et al., 2020; Wennman et al., 2019).

Sample Rates vs. Comparison Sample Rates

In DP1, survivors' mean TST (M = 6.78, SD = 1.21) was not significantly different from comparison sample rates (M = 6.71, SD = 0.89), $t(263) = 0.51$, $p = .614$. Survivors' mean SE (M = 91.21%, SD = 4.56) was significantly better than comparison sample rates (M = 85.7%, SD = 6.1), $t(263) = 6.77$, $p < .001$. Partners' mean TST (M = 6.33, SD = 1.25) was not statistically different from comparison sample rates (M = 6.09, SD = 1.13), $t(239) = 1.42$, $p = .158$. Partners' mean SE (M = 92.07, SD = 3.74) was significantly better than comparison sample rates (M = 82.40, SD = 9.12), $t(235.48) = 11.65$, $p \leq .001$.

Sample Rates vs. Recommendations

In DP1, survivors' mean TST (M = 6.78, SD = 1.21) was not statistically different than the recommended 7 hours for adults, $t(66) = -1.49$, $p = .142$). However, partners' mean TST (M = 6.33, SD = 1.25) was significantly less than the recommended 7 hours, $t(63) = -4.36$, $p < .001$. While survivors' mean TST was not statistically different from 7 hours, approximately 55% of survivors had a mean TST less than 7 hours in DP1. Seventy-two percent of partners had a mean TST less than 7 hours. Averaged across DP1, both survivors (M = 13.76; SD = 5.24; $t(66) = 19.93$, $p < .001$) and partners (M = 11.89, SD = 4.67; $t(63) = 18.64$, $p < .001$) had significantly more awakenings than what is considered good sleep quality (≤1). In fact, no survivors and no partners had ≤ 1 awakening on average. The average WASO for survivors (M = 39.47, SD = 20.94; $t(66) = 7.61$, $p < .001$) and partners (M = 33.16, SD = 14.23;

$t(63) = 7.40$, $p < .001$) was significantly greater than what is considered good sleep quality (≤ 20 minutes). Only ~8% of survivors and ~17% of partners had a mean WASO ≤ 20 minutes. Survivors' ($M = 91.21$, $SD = 4.56$; $t(66) = 11.14$, $p < .001$) and partners' ($M = 92.07$, $SD = 3.74$; $t(63) = 15.15$, $p < .001$) mean SE was significantly better than the 85% considered indicative of good sleep quality. Most survivors (~94%) and partners (~94%) had a mean SE ≥ 85%.

Taken together, in DP1, partners' mean TST and survivors' and partners' mean awakenings and WASO did not meet recommendations for sleep duration and sleep quality. Survivors' mean TST did not significantly differ from the recommended 7 hours; however, most survivors slept less than 7 hours on average across DP1. Despite difficulties with sleep duration and sleep maintenance, both survivors' and partners' mean SE exceeded the cut-off of 85% considered to be indicative of good quality sleep.

Survivors vs. Partners

In DP1 at the between-person level, two of the five objective sleep disturbance outcomes showed statistically significant, positive, and small-medium bivariate correlations between survivors and partners. Specifically, survivors' and partners' sleep period length ($r = 0.37$, $p = .005$) and TST ($r = 0.36$, $p = .004$) were significantly correlated to one another. Survivors' and partners' awakenings ($r = 0.21$, $p = .062$), WASO ($r = 0.34$, $p = .051$), and SE ($r = 0.37$, $p = .085$) were not significantly correlated to one another's. Therefore, survivors who demonstrated longer sleep

periods and TST across DP1 were paired with partners who also demonstrated longer sleep periods and TST across DP1.

In DP1 at the within-person level, bivariate correlations demonstrated significant and positive correlations for one of the five objective sleep disturbance outcomes between survivors and partners. Survivors' and partners' TST were (r = 0.09, p = .024) significantly correlated to one another and this correlation was small. Survivors' and partners' sleep period (r = 0.08, p = .062), awakenings (r = 0.03, p = .317), WASO (r = 0.01, p = .787), and SE (r = 0.08, p = .128) were not significantly correlated to one another at the within-person level. Therefore, in DP1, on nights survivors demonstrated longer TST, their partners also demonstrated longer TST.

See Table 5 for *Paired Samples T-tests of Mean Differences Between Survivors and Partners*. Paired samples t-tests revealed statistically significant differences between the mean levels of survivors and partners for four of the five outcomes. On average, survivors' sleep period (M = 7.37, SD = 1.20) was significantly longer than that of partners (M = 6.88, SD = 1.25), $t(60) = 2.74$, p = .008. Survivors' mean TST (M = 6.74, SD = 1.24) was also significantly longer than that of partners (M = 6.33, SD = 1.27), $t(60) = 2.23$, p = .030. Survivors demonstrated significantly more awakenings (M = 13.51; SD = 5.18) than partners (M = 11.79, SD = 4.72) on average, $t(60) = 2.15$, p = .036). Survivors also demonstrated significantly more WASO (M = 38.32, SD = 19.66) than partners (M = 33.03, SD = 14.56) on average, $t(60) = 2.02$, p = .048. The difference between survivors' (M = 91.31, SD = 4.58) and partners' mean SE (M = 92.11, SD = 3.82) was not statistically significant, $t(60) = -1.31$, p = .195. Taken

together, while survivors had longer sleep periods and more TST than partners, survivors had greater difficulties with sleep maintenance than did partners.

Diary Period 2 (First Post-Treatment Mammogram)

See Table 3 (between-person) and Table 4 (within-person) for bivariate correlations and descriptive statistics for key variables from DP2.

Sample Rates vs. Comparison Sample Rates

In DP2, survivors' mean TST (M = 6.74, SD = 1.61) was not statistically different from comparison sample rates (M = 6.71, SD = 0.89), $t(246) = 0.177$, $p = .860$. Survivors' mean SE (M = 92.03, SD = 3.97) was significantly better than comparison sample rates (M = 85.70, SD = 6.1), $t(246) = 6.97$, $p < .001$. Partners' mean TST (M = 6.57, SD = 1.40) was significantly longer than comparison sample rates (M = 6.09, SD = 1.13), $t(223) = 2.47$, $p = .014$. Partners' mean SE (M = 92.03, SD = 3.70) was significantly better than comparison sample rates (M = 82.40, SD = 9.12), $t(191.00) = 11.08$, $p \leq .001$.

Sample Rates vs. Recommendations

In DP2, survivors' mean TST (M = 6.74, SD = 1.61) did not statistically differ from the recommended 7 hours for adults, $t(49) = -1.14$, $p = .259$). However, partners' mean TST (M = 6.57, SD = 1.40) was significantly less than the recommended 7 hours for adults, $t(47) = -2.11$, $p = .040$. Approximately 54% of survivors and 60% of partners slept less than 7 hours on average in DP2. Both survivors (M = 12.71; SD =

6.22; $t(49) = 13.31$, $p < .001$) and partners ($M = 12.00$, $SD = 5.22$; $t(47) = 14.60$, $p < .001$) had significantly more awakenings on average than what is considered good sleep quality (≤1). Indeed, no survivors or partners had ≤ 1 awakenings on average. The mean WASO for survivors ($M = 34.71$, $SD = 17.14$; $t(49) = 6.07$, $p < .001$) and partners ($M = 35.10$, $SD = 15.00$; $t(47) = 6.98$, $p < .001$) was significantly greater than what is considered good sleep quality (≤ 20 minutes). Indeed, only ~18% of survivors and ~15% of partners had a mean WASO ≤ 20 minutes. Survivors' ($M = 92.03$, $SD = 3.97$; $t(49) = 12.53$, $p < .001$) and partners' ($M = 92.03$, $SD = 3.70$; $t(47) = 13.17$, $p < .001$) mean SE was significantly better than the 85% considered to be indicative of good sleep quality. Most (~96%) of survivors and most (~96%) of survivors had a mean SE ≥ 85%.

In DP2, partners' mean TST and survivors' and partners' mean awakenings and WASO did not meet recommendations for sleep duration and sleep quality. While survivors' mean TST did not significantly differ from the recommended 7 hours, most slept less than 7 hours on average. Despite these difficulties with sleep duration and sleep maintenance, both survivors' and partners' mean SE exceeded 85%, which is indicative of good quality sleep.

Survivors vs. Partners

In DP2 at the between-person level, bivariate correlations revealed significant, positive, and medium-sized associations between survivors and partners for three of the five objective sleep disturbance outcomes. Survivors' and partners' mean sleep

period (r = 0.42, p = .013), TST (r = 0.40, p = .024), and WASO (r = 0.09, p = .046) were related to one another. Awakenings (r = 0.07, p = 0.57) and SE (r = 0.01, p = .974) were not significantly correlated between survivors and partners at the between-person level. Therefore, survivors who demonstrated longer sleep periods and longer TST across DP2 were paired with partners who also demonstrated longer sleep periods and longer TST across DP2. Across DP2, survivors who demonstrated greater WASO were paired with partners who also demonstrated greater WASO.

In DP2 at the within-person level, three of the five objective sleep disturbance outcomes showed statistically significant and positive bivariate correlations between survivors and partners. Survivors' and partners' sleep period length (r = 0.09, p = .043), TST (r = 0.11, p .029), and SE (r = 0.10, p = .013) were significantly correlated. Survivor's and partners' number of awakenings (r = 0.06, p = .086) and WASO (r = 0.05, p = .703) were not significantly correlated with one another's at the within-person level. Therefore, on nights survivors demonstrated longer sleep periods and TST, their partners also demonstrated longer sleep periods and TST. On nights survivors demonstrated better SE, so did their partners.

See Table 5 for *Paired Samples t-tests of Mean Differences Between Survivors and Partners*. Paired samples t-tests failed to reveal statistically significant differences between the mean levels of survivors and partners for all five outcomes (all ps ≥ .091).

Before vs. After Mammogram

See Table 6 for *Paired Samples t-tests of Mean Differences Between Before and After the Mammogram*. We performed mean differences between objective sleep disturbance averaged across the nights before the mammogram, including the eve of the mammogram appointment, with objective sleep disturbance averaged across the nights after the mammogram. Paired samples t-tests failed to reveal statistically significant differences between mean levels of any of the objective sleep outcomes before versus after the mammogram for both survivors and partners (all *p*s ≥ .456).

Diary Period 1 vs. Diary Period 2

See Table 7 for *Paired Samples t-tests of Mean Differences Between DP1 and DP2*. We performed mean differences between participants' objective sleep difficulties in DP1 with their own objective sleep difficulties in DP2. There were no statistically significant differences between partners' mean levels of any of the outcomes at DP1 versus DP2 (all *p*s ≥ .085).

As an interim summary of the descriptive findings, in both DP1 and DP2, survivors' and partners' mean SE was better than comparison sample rates. In DP2, partners' mean TST was also better than comparison sample rates. In both DP1 and DP2, survivors' and partners' mean number of awakenings and mean WASO were greater than what is considered good quality sleep. Despite these difficulties with sleep maintenance, in both DP1 and DP2, survivors' and partners' mean SE was significantly higher than the 85% suggestive of good quality sleep. In both periods,

partners' mean TST was significantly less than the 7 hours recommended for adults, but this was not true for survivors in either period (National Sleep Foundation, 2020). In DP1 and DP2, survivors' and partners' sleep period length and TST were positively associated with one another's at the between-person level. In DP1 and DP2, survivors' and partners' TST were positively associated with one another at the within-person level. In DP2 only, survivors' and partners' mean sleep period length and SE were also positively associated with one another's at the between-person level. In DP1 significant differences emerged between survivors and partners in mean levels of four of the five objective sleep disturbance outcomes. Survivors' mean sleep period length and TST were significantly longer than partners, but they demonstrated more awakenings and WASO on average. In DP2, no significant differences were observed between survivors and partners for mean levels for any of the outcomes.

Aim 2: Examine Between-Person Associations between FCR and Objective Sleep Disurbance

Diary Period 1 (Completion of Adjuvant Treatment)

See Table 8 for the *Multilevel Regression Results of the Between-Person Links Between Daily FCR and Objective Sleep Disturbance for DP1*. In DP1, there were no significant between-person associations between FCR and objective sleep disturbance after controlling for average daytime sleep, for survivors or partners, actor or cross-partner effects (all *p*s ≥ .184).

Diary Period 2: First Post-Treatment Mammogram)

See Table 9 for the *Multilevel Regression Results of the Between-Person Links Between Daily FCR and Objective Sleep Disturbance for DP1*. Similar to DP1, in DP2, there were no significant between-person associations between FCR and the objective sleep disturbance outcomes after controlling for average daytime sleep, for survivors or partners, actor or cross-partner effects (all *p*s ≥ .224).

Aim 3: Examine Daily, Within-Person and Within-Couple Associations between FCR and Objective Sleep Disturbance

Diary Period 1 (Completion of Adjuvant Treatment)

See Table 10 for *Multilevel Regression Results of the Daily, Within-Person Links Between Daily FCR and Objective Sleep Disturbance for DP1.* In DP1, there were no significant within-person associations between FCR reported in the evening and the objective sleep disturbance outcomes that night, after controlling for any daytime sleep from earlier that day. This pattern is true for survivors and partners, actor and cross-partner effects (all *p*s ≥ .132).

Diary Period 2 (First Post-Treatment Mammogram)

See Table 11 for *Multilevel Regression Results of the Daily, Within-Person Links Between Daily FCR and Objective Sleep Disturbance for DP2*. The survivor actor effect for sleep period length was statistically significant and negative (γ = -4.45, p = .024), but small in size (standardized γ = -0.11). The significant survivor actor effect indicates that on a day that a survivor reported more FCR than is typical for

them, they also experienced a shorter sleep period (minutes between sleep onset and offset) that night, after controlling for any time they slept that same day. The survivor actor effect for TST was also statistically significant, negative ($\gamma = -3.80$, $p = .028$) and small in size (standardized $\gamma = -0.10$). Therefore, on a day that a survivor reported more FCR than is typical for them, they experienced shorter sleep duration that night, after controlling for any time they slept that day.

Apart from these two significant survivor actor effects, there were no significant daily, within-person associations between FCR and objective sleep disturbance outcomes, for survivors or partners, actor or cross-partner effects (the remaining ps $\geq .082$).

Table 1 Between-Person Bivariate Correlations and Descriptive Statistics for Key Variables from Diary Period 1

	1	2	3	4	5	6
1. Fear of cancer recurrence	(0.21)	-0.03	-0.03	-0.12	-0.50	0.00
2. Sleep period	-0.01	(0.37**)	0.98***	0.18	-0.04	0.35**
3. Total sleep time	0.01	0.96***	(0.36**)	0.05	-0.22	0.50***
4. Awakenings	-0.18	0.22	-0.01	(0.21)	0.72***	-0.60***
5. Wake after sleep onset	-0.06	0.10	-0.19	0.77***	(0.34)	-0.94***
6. Sleep efficiency	0.05	0.19	0.46***	-0.69***	-0.98***	(0.37)
M DP1 (Survivor/Partner)	2.09/1.32	449.35/414.73	410.42/381.41	13.74/11.98	38.93/33.29	91.39/92.09
SD DP1 (Survivor/Partner)	2.20/2.43	67.83/69.87	68.83/71.56	5.05/4.48	19.69/12.66	4.34/3.48
Range DP1 (Survivor/Partner)	0-20/0-21	161-1208/161-933	88-1208/85-824	0-48/0-58	0-245/0-261	27-100/41-100

Note. Top panel: Bivariate between-person correlations among variables. Correlations among survivors' variables are below the diagonal (shaded light gray), correlations among partners' variables are above the diagonal (shaded dark gray), and correlations between survivors' and partners' variables are in parentheses along the diagonal. *$p < .05$, **$p \leq .01$, ***$p \leq .001$. Bottom panel: Means and SDs for survivors' and partners' variables are before and after the slash, respectively (i.e., survivor/partner).

Table 2 Within-Person Bivariate Correlations for Key Variables from Diary Period 1

	1	2	3	4	5	6
1. Fear of cancer recurrence	(0.23***)	-0.02	-0.02	-0.01	-0.36	0.01
2. Sleep period	-0.01	(0.08)	0.98***	0.60***	0.60***	-0.28***
3. Total sleep time	-0.01	0.98***	(0.09*)	0.49***	0.41***	-0.08
4. Awakenings	0.01	0.54***	0.41***	(0.03)	0.72***	-0.58***
5. Wake after sleep onset	0.01	0.54***	0.34***	0.77***	(0.01)	-0.88***
6. Sleep efficiency	0.01	-0.18***	0.02***	-0.59***	-0.87***	(0.08)
SD DP1 (Survivor/Partner)	2.53/2.07	100.92/101.09	90.69/93.53	6.01/5.57	22.98/24.27	4.21/4.69

Note. Top panel: Bivariate within-person correlations among variables. Correlations among survivors' variables are below the diagonal (shaded light gray), correlations among partners' variables are above the diagonal (shaded dark gray), and correlations between survivors' and partners' variables are in parentheses along the diagonal. *$p < .05$, **$p \leq .01$, ***$p \leq .001$. Bottom panel: SDs for survivors' and partners' variables at the within-person level are before and after the slash, respectively (i.e., survivor/partner).

Table 3 Between-Person Bivariate Correlations and Descriptive Statistics for Key Variables from Diary Period 2

	1	2	3	4	5	6
1. Fear of cancer recurrence	(0.31**)	-0.09	-0.04	-0.24	-0.28*	0.24*
2. Sleep period	0.05	(0.42*)	0.99***	0.01	-0.09	0.46***
3. Total sleep time	0.02	0.98***	(0.40*)	-0.13	-0.26*	0.60***
4. Awakenings	0.02	0.19	0.03	(0.07)	0.81***	-0.73***
5. Wake after sleep onset	0.18	0.02	-0.16	0.90***	(0.05)	-0.90***
6. Sleep efficiency	-0.13	0.37*	0.53***	-0.72***	-0.90***	(0.01)
M DP2 (Survivor/Partner)	1.74/0.90	442.38/429.24	407.19/394.57	12.84/11.97	35.17/34.63	92.02/92.18
SD DP2 (Survivor/Partner)	1.65/1.60	86.64/77.28	87.81/79.70	5.91/5.05	16.13/13.43	3.85/3.45
Range DP2 (Survivor/Partner)	0-24/0-17	160-890/162-912	124-815/143/834	0-48/0-48	0-224/0-386	65-100/43-100

Note. Top panel: Bivariate between-person correlations among variables. Correlations among survivors' variables are below the diagonal (shaded light gray), correlations among partners' variables are above the diagonal (shaded dark gray), and correlations between survivors' and partners' variables are in parentheses along the diagonal. *$p < .05$, **$p \leq .01$, ***$p \leq .001$. Bottom panel: Means and SDs for survivors' and partners' variables are before and after the slash, respectively (i.e., survivor/partner).

Table 4 Within-Person Bivariate Correlations for Key Variables from Diary Period 2

	1	2	3	4	5	6
1. Fear of cancer recurrence	(0.32***)	0.01	-0.01	-0.04	0.01	0.01
2. Sleep period	-0.09*	(0.09*)	0.98***	0.63***	0.65***	-0.41***
3. Total sleep time	-0.08*	0.98***	(0.11*)	0.53***	0.47***	-0.23***
4. Awakenings	-0.05	0.63***	0.53***	(0.06)	0.72***	-0.83***
5. Wake after sleep onset	-0.07	0.66***	0.51***	0.80***	(0.09*)	-0.90***
6. Sleep efficiency	0.05	-0.27***	-0.11*	-0.60***	-0.83***	(0.10*)
SD DP2 (Survivor/Partner)	2.67/1.78	106.03/112.89	93.05/97.22	6.03/5.94	21.95/27.53	3.80/4.56

Note. Top panel: Bivariate within-person correlations among variables. Correlations among survivors' variables are below the diagonal (shaded light gray), correlations among partners' variables are above the diagonal (shaded dark gray), and correlations between survivors' and partners' variables are in parentheses along the diagonal. *$p < .05$, **$p \leq .01$, ***$p \leq .001$. Bottom panel: SDs for survivors' and partners' variables at the within-person level are before and after the slash, respectively (i.e., survivor/partner).

Table 5 Paired Samples T-tests of Mean Differences Between Survivors and Partners

Outcome	Survivor		Partner		*t*	*p*
	Mean	***SD***	**Mean**	**SD**		
			DP1 (*n* = 61)			
Sleep period	7.37	1.20	6.88	1.25	2.74	.008
Total sleep time	6.74	1.24	6.33	1.27	2.23	.030
Awakenings	13.51	5.18	11.79	4.72	2.15	.036
Wake after sleep onset	38.32	19.66	33.03	14.56	2.02	.048
Sleep efficiency	91.31	4.58	92.11	3.82	-1.31	.195
			DP2 (*n* = 44)			
Sleep period	7.48	1.55	7.07	1.24	1.73	.091
Total sleep time	6.90	1.56	6.48	1.22	1.72	.092
Awakenings	12.64	6.25	12.12	5.23	0.44	.659
Wake after sleep onset	34.69	17.48	35.03	14.75	-0.10	.920
Sleep efficiency	92.19	4.12	92.07	3.33	0.15	.879

Table 6 Paired Samples T-tests of Mean Differences Between Before and After the Mammogram

Outcome	Before		After		*t*	*p*
	Mean	***SD***	**Mean**	**SD**		
	Survivors (*n* =48)					
Sleep period	7.38	1.54	7.50	1.73	-0.75	.456
Total sleep time	6.81	1.55	6.90	1.71	-0.75	.458
Awakenings	12.79	6.23	12.87	7.21	-0.14	.893
Wake after sleep onset	34.51	18.57	35.69	21.38	-0.54	.594
Sleep efficiency	92.14	4.29	91.87	5.36	0.61	.543
	Partners (*n* = 42)					
Sleep period	7.06	1.40	7.09	1.46	-0.18	.860
Total sleep time	6.47	1.31	6.49	1.38	-0.15	.880
Awakenings	12.53	6.59	12.59	5.84	-0.09	.930
Wake after sleep onset	35.57	18.83	36.06	20.15	-0.16	.872
Sleep efficiency	91.98	3.60	92.01	3.89	-0.07	.948

Table 7 Paired Samples T-tests of Mean Differences Between DP1 and DP2

Outcome	DP1		DP2		*t*	*p*
	Mean	***SD***	**Mean**	**SD**		
Survivors (*n* = 48)						
Sleep period	7.48	1.31	7.32	1.65	1.04	.302
Total sleep time	6.82	1.34	6.73	1.64	0.65	.522
Awakenings	13.78	5.75	12.86	6.30	1.41	.165
Wake after sleep onset	39.98	22.20	35.27	17.26	1.50	.140
Sleep efficiency	91.07	5.10	91.90	3.99	-1.32	.193
Partners (*n* =43)						
Sleep period	6.80	1.14	7.00	1.26	-1.76	.085
Total sleep time	6.24	1.13	6.41	1.26	-1.67	.103
Awakenings	11.63	5.15	11.95	5.06	-0.57	.570
Wake after sleep onset	33.62	15.10	35.27	15.39	-0.84	.407
Sleep efficiency	92.00	3.73	91.89	3.69	0.27	.792

Table 8 Multilevel Regression Results of the Between-Person Links Between Daily FCR and Objective Sleep Disturbance for DP1

Outcome/Effect	Estimate	*p*	95% CI	
			Lower	Upper
Survivors				
Sleep period (minutes)				
Actor effect	-0.78	.868	-10.53	9.05
Cross-partner effect	5.08	.276	-4.13	14.30
Total sleep time (mins.)				
Actor effect	-0.48	.928	-10.06	9.17
Cross-partner effect	5.04	.256	-3.68	14.00
Awakenings				
Actor effect	-0.44	.216	-1.16	0.21
Cross-partner effect	0.05	.888	-0.60	0.70
Wake after sleep onset (mins.)				
Actor effect	-1.27	.346	-4.05	1.30
Cross-partner effect	0.56	.658	-1.90	2.95
Sleep efficiency (%)				
Actor effect	0.28	.364	-0.32	0.86
Cross-partner effect	-0.01	.982	-0.54	0.54
Partners				
Sleep period (minutes)				
Actor effect	-1.65	.710	-10.05	6.51
Cross-partner effect	3.25	.474	-5.69	12.51
Total sleep time (mins.)				
Actor effect	-3.73	.372	-12.11	4.57
Cross-partner effect	4.22	.350	-4.55	13.17
Awakenings				
Actor effect	-0.13	.636	-0.67	0.39
Cross-partner effect	-0.21	.460	-0.78	0.35
Wake after sleep onset (mins.)				
Actor effect	0.25	.752	-1.31	1.82
Cross-partner effect	-0.57	.486	-2.17	1.02
Sleep efficiency (%)				
Actor effect	-0.10	.624	-0.51	0.31
Cross-partner effect	0.28	.184	-0.14	0.70

Note. The models for each outcome controlled for time, daytime sleep, and estimated a full unstructured random effect structure at level-1 and a random effect structure (e.g., random effects) for all actor and cross-partner effects. *p* = two-tailed *p*-value. CI = credibility interval.

Table 9 Multilevel Regression Results of the Between-Person Links between Daily FCR and Objective Sleep Disturbance for DP2

Outcome/Effect	Estimate	*p*	95% CI	
			Lower	Upper
Survivors				
Sleep period (minutes)				
Actor effect	3.87	.686	-15.27	23.96
Cross-partner effect	-5.36	.630	-28.63	18.77
Total sleep time (mins.)				
Actor effect	2.83	.778	-16.46	22.82
Cross-partner effect	-5.71	.630	-28.91	18.56
Awakenings				
Actor effect	-0.12	.846	-1.41	1.15
Cross-partner effect	0.50	.500	-1.02	2.00
Wake after sleep onset (mins.)				
Actor effect	1.44	.414	-2.02	5.01
Cross-partner effect	0.45	.814	-3.79	4.56
Sleep efficiency (%)				
Actor effect	-0.23	.574	-1.06	0.59
Cross-partner effect	-0.17	.714	-1.18	0.82
Partners				
Sleep period (minutes)				
Actor effect	-1.68	.882	-23.94	21.50
Cross-partner effect	6.66	.456	-11.20	24.44
Total sleep time (mins.)				
Actor effect	0.99	.928	-22.35	24.69
Cross-partner effect	6.53	.474	-11.86	24.92
Awakenings				
Actor effect	-0.78	.252	-2.13	0.57
Cross-partner effect	-0.35	.514	-1.38	0.77
Wake after sleep onset (mins.)				
Actor effect	-2.19	.270	-5.94	1.64
Cross-partner effect	0.04	.976	-2.98	3.13
Sleep efficiency (%)				
Actor effect	0.57	.224	-0.35	1.54
Cross-partner effect	0.17	.644	-0.57	0.94

Note. The models for each outcome controlled for time, daytime sleep, and estimated a full unstructured random effect structure at level-1 and a random effect structure (e.g., random effects) for all actor and cross-partner effects. *p* = two-tailed *p*-value. CI = credibility interval.

Table 10 Multilevel Regression Results of the Daily, Within-Person Links Between Daily FCR and Objective Sleep Disturbance for DP1

Outcome/Effect	Estimate	*p*	95% CI	
			Lower	Upper
Survivors				
Sleep period (minutes)				
Actor effect	0.54	.788	-3.58	4.65
Cross-partner effect	-1.15	.534	-4.80	2.78
Total sleep time (mins.)				
Actor effect	-0.18	.922	-4.11	3.56
Cross-partner effect	-1.57	.334	-4.81	1.86
Awakenings				
Actor effect	0.001	.992	-0.17	0.16
Cross-partner effect	0.09	.480	-0.17	0.37
Wake after sleep onset (mins.)				
Actor effect	0.06	.872	-0.62	0.92
Cross-partner effect	1.21	.216	-0.86	2.99
Sleep efficiency (%)				
Actor effect	-0.02	.810	-0.24	0.12
Cross-partner effect	-0.20	.132	-0.46	0.06
Partners				
Sleep period (minutes)				
Actor effect	-2.50	.460	-9.87	4.77
Cross-partner effect	0.53	.788	-3.12	4.05
Total sleep time (mins.)				
Actor effect	-1.63	.456	-7.07	3.27
Cross-partner effect	0.46	.790	-2.86	3.65
Awakenings				
Actor effect	-0.10	.596	-0.49	0.28
Cross-partner effect	0.01	.910	-0.18	0.20
Wake after sleep onset (mins.)				
Actor effect	0.48	.612	-1.50	2.40
Cross-partner effect	0.47	.552	-1.11	2.09
Sleep efficiency (%)				
Actor effect	-0.04	.688	-0.25	0.14
Cross-partner effect	-0.12	.940	-0.31	0.30

Note. The models for each outcome controlled for time, daytime sleep, and estimated a full unstructured random effect structure at level-1 and a random effect structure (e.g., random effects) for all actor and cross-partner effects. *p* = two-tailed *p*-value. CI = credibility interval.

Table 11 Multilevel Regression Results of the Daily, Within-Person Links Between Daily FCR and Objective Sleep Disturbance for DP2

Outcome/Effect	Estimate	*p*	95% CI	
			Lower	Upper
Survivors				
Sleep period (minutes)				
Actor effect	-4.45	.024	-8.60	-0.58
Cross-partner effect	2.04	.542	-3.31	9.41
Total sleep time (mins.)				
Actor effect	-3.80	.028	-7.50	-0.34
Cross-partner effect	1.60	.590	-3.15	8.22
Awakenings				
Actor effect	-0.18	.140	-0.43	0.04
Cross-partner effect	0.23	.382	-0.18	0.83
Wake after sleep onset (mins.)				
Actor effect	-0.63	.082	-1.40	0.06
Cross-partner effect	0.36	.576	-0.66	1.74
Sleep efficiency (%)				
Actor effect	0.09	.122	-.03	0.22
Cross-partner effect	-0.03	.818	-0.22	0.20
Partners				
Sleep period (minutes)				
Actor effect	0.70	.828	-6.41	8.51
Cross-partner effect	0.15	.952	-5.01	5.73
Total sleep time (mins.)				
Actor effect	0.82	.774	-5.23	8.16
Cross-partner effect	0.63	.824	-4.78	6.25
Awakenings				
Actor effect	-0.12	.452	-0.47	0.19
Cross-partner effect	-0.002	.988	-0.23	0.24
Wake after sleep onset (mins.)				
Actor effect	-0.10	.918	-2.84	2.03
Cross-partner effect	-0.11	.822	-1.01	0.86
Sleep efficiency (%)				
Actor effect	-0.01	.922	-0.26	0.24
Cross-partner effect	0.05	.472	-0.10	0.20

Note. The models for each outcome controlled for time, daytime sleep, and estimated a full unstructured random effect structure at level-1 and a random effect structure (e.g., random effects) for all actor and cross-partner effects. *p* = two-tailed *p*-value. CI = credibility interval.

Chapter 5

DISCUSSION

Sleep disturbance is prevalent among BC survivors (J. Savard et al., 2001, 2009, 2011) as well as their intimate partners (Chang et al., 2007; Dhruva, Lee, et al., 2012). Prior studies of objective sleep disturbance among BC survivors were limited by actigraphy measurement of only two to seven days and as the length of actigraphy recording increases, sleep disturbance outcomes change (Budhrani et al., 2015). Moreover, most studies of objective sleep disturbance among BC survivors were limited to during or shortly after the completion of treatment. Few studies have assessed objective sleep disturbance in partners of cancer survivors (cf. Carney et al., 2011; Dhruva, Lee, et al., 2012) and we are aware of no published studies examining objective sleep disturbance in the partners of BC survivors specifically. In contrast, the present study used actigraphy to assess objective sleep disturbance among early-stage BC survivors and their partners in two, 21-day periods post-treatment: the completion of adjuvant treatment (DP1) and the first, post-treatment mammogram (DP2). The objective sleep disturbance parameters examined were sleep period length, total (TST), number of awakenings, wake after sleep onset (WASO), and sleep efficiency (SE).

Aim 1: Describe Objective Sleep Disturbance in BC Survivors and Their Partners after Adjuvant Treatment and at the First, Post-Treatment Mammogram

Consistent with hypotheses, across both periods, partners demonstrated significantly less TST than the recommended 7 hours for adults (National Sleep Foundation, 2020). However, contrary to hypotheses, this effect was not significant for survivors in either period. Consistent with hypotheses, in both periods, survivors and partners demonstrated significantly more awakenings and greater WASO on average than what is considered good quality sleep (Ohayon et al., 2017). Contrary to hypotheses, in both DP1 and DP2, survivors' and partners' mean SE was significantly better than 85%, which is indicative of good sleep quality (Lauderdale et al., 2006; Ohayon et al., 2017).

Total sleep time varies among BC survivors with some studies reporting TST < 6 hours (Otte et al., 2011) and others reporting TST up to 8 hours (Berger et al., 2003). Therefore, that survivors' mean TST did not significantly differ from 7 hours in both periods may be consistent with prior studies of objective sleep disturbance in BC survivorship. That survivors demonstrated more awakenings and greater WASO on average as compared to indices for good sleep quality is consistent with prior research. Across studies of objective sleep disturbance in BC survivors, awakenings and WASO are the parameters most impacted (Budhrani et al., 2015). That survivors demonstrated mean SE greater than 85% is also consistent with existing evidence (Budhrani et al., 2015). A review of objective sleep disturbance among BC survivors concluded that SE

was the least impacted parameter and that in most studies, average SE was > 85% (Budhrani et al., 2015).

This is the first known study of objective sleep disturbance among partners of BC survivors. Consistent with hypotheses, the results suggest that partners also experienced elevated levels of objective sleep disturbance – difficulties with sleep duration and maintenance. Interestingly, when compared to recommendations for sleep quantity and quality, only one difference emerged between the patterns of results for survivors and partners. That is, in both periods, partners' mean TST was significantly less than 7 hours, but this was not true for survivors.

Taken together, these results suggest that both BC survivors and partners have elevated levels of objective sleep disturbance – particularly difficulties with sleep maintenance. Despite difficulties with sleep maintenance, SE remains unaffected. Partners also demonstrate difficulties with sleep duration.

No published studies have compared objective sleep disturbance between BC survivors and their partners. In both periods, survivors' and partners' sleep period length and TST were positively related to one another at the between-person level. For DP2 only, survivors' and partners' WASO were positively related at the between-person level. In both periods, survivors' and partners' TST were positively related to one another at the within-person level. For DP2 only, survivors' and partners' sleep period length and SE were also positively related to one another at the within-person level. Only for awakenings were no significant correlations observed (in DP1 or DP2, at the between- or within-person level). Taken together, consistent with predictions

and prior reports of sleep concordance in couples (including in couples coping with cancer; Carney et al., 2011; Gunn et al., 2015; Lee et al., 2018; Meadows et al., 2009), objective sleep parameters, particularly sleep period length and TST, were correlated within couples coping with BC. That no correlations were observed for number of awakenings contrasts predictions as well as prior work in couples demonstrating that intimate partners' minute-by-minute sleep versus awake states match for as much as 88% of the night (Gunn et al., 2015).

In DP1, survivors' mean sleep period length and TST were significantly longer than those of partners. Also in DP1, survivors had significantly more awakenings and WASO on average than did partners. Therefore, in DP1, despite having longer sleep periods and duration, survivors tended to have more difficulties with sleep maintenance than did partners. However, these differences were limited to DP1. In DP2 there were no significant differences between survivors' and partners' mean levels of objective sleep disturbance. More correlations and fewer mean differences were found between survivors' and partner' sleep in DP2 as compared to DP1. Therefore, survivors' and partners' objective sleep disturbance may be more tightly coupled at the first, post-treatment mammogram than at the completion of adjuvant treatment.

This is the first known study to assess objective sleep disturbance at the first, post-treatment mammogram. There were no significant mean differences between sleep outcomes from before to after the mammogram, for survivors or partners. Therefore, despite being conceptualized as an impending threat, the results suggest

that objective sleep is not more disturbed in the nights leading up to the first, post-treatment mammogram.

We compared survivors' and partners' objective sleep disturbance at the completion of adjuvant treatment with their own objective sleep disturbance at the first, post-treatment mammogram. We did not make hypotheses for these comparisons as there is little research on objective sleep disturbance in BC survivors and none in partners in the post-treatment period. There were no significant differences between mean levels of any of the outcomes from DP1 to DP2, for survivors or partners. Therefore, survivors' and partners' levels of objective sleep disturbance are consistent across the first year post-diagnosis. This finding is consistent with prior research among BC survivors demonstrating that objective sleep remains poor up to one year post-treatment (Budhrani et al., 2015).

In sum, in the first year post-diagnosis, both BC survivors and their partners demonstrated difficulty staying asleep and partners demonstrated difficulty with sleep duration. However, both survivors' and partners' sleep efficiency remained high. Objective sleep disturbance was concordant in couples coping with early-stage BC, particularly at the first, post-treatment mammogram, which is approximately 12 months post-diagnosis. Levels of objective sleep disturbance persisted across early survivorship and were not worse in the nights leading up to the first, post-treatment mammogram.

Aim 2 and Aim 3: Examine Between-Person and Daily, Within-Person Associations between FCR and Objective Sleep Disturbance

FCR is related to self-reported sleep disturbance in both BC survivors and their partners (Alfano et al., 2011; Dupont et al., 2014; Hall et al., 2014; Levesque et al., 2022; Lowery-Allison et al., 2018; Perndorfer et al., 2022, in press; Taylor et al., 2012). The present study is the first to examine associations between FCR and *objective* sleep disturbance in early-stage BC survivors, their partners, and at the dyad level. We examined the between- and within-person association between daily FCR and objective sleep disturbance in two, 21-day periods post-treatment: the completion of adjuvant treatment (DP1) and the first, post-treatment mammogram (DP2). We examined these associations from the dyadic level – including associations between one's own FCR (actor effects) and one's own objective sleep disturbance and between one's own FCR and one's partners' FCR (cross-partner effects) – see Figure 2.

In both DP1 and DP2, there were no significant between-person associations between FCR and objective sleep disturbance, after controlling for average levels of daytime sleep (for survivors or partners, actor or cross-partner effects). Turning to the within-person associations, at the first, post-treatment mammogram (DP2), survivors' FCR was significantly and negatively associated with their own sleep period length and TST that night, controlling for any daytime sleep from that same day. Therefore, on a day that survivors reported more FCR than is typical for them, they also demonstrated shorter sleep periods and shorter sleep duration that night, after controlling for any naps they took that same day. Apart from these two significant

actor effects in DP2, there were no significant within-person associations between FCR and objective sleep disturbance (for survivors or partners, actor or cross-partner effects, DP1 or DP2).

The results of the current study suggest that FCR is not robustly related to objective sleep disturbance in early-stage BC survivors or their partners. These findings contrast prior work on the relationship between FCR and self-reported sleep disturbance in which greater FCR is related to greater sleep disturbance (Alfano et al., 2011; Dupont et al., 2014; Hall et al., 2014; Lowery-Allison et al., 2018; Perndorfer et al., 2022; Taylor et al., 2012). It is perhaps unsurprising that in large part, FCR was not significantly associated with objective sleep disturbance as self-report and objective measures of sleep are not strongly correlated (Chen et al., 2015), including in BC survivors (Budhrani et al., 2015; Moore et al., 2015). Furthermore, self-report and objective measures of sleep have unique correlates (Lauderdale et al., 2016), including in BC survivors (Dhruva, Paul, et al., 2012). Therefore, self-report and objective measures of sleep may tap different facets of sleep disturbance. Consistent with this, self-report of sleep is considered subjective.

In other work, we previously demonstrated associations between global FCR and daily subjective sleep disturbance in the expected direction, for both BC survivors and partners, actor and cross-partner effects, at the completion of adjuvant treatment and the first, post-treatment mammogram (Perndorfer et al., 2022). The sample for the current study included the participants previously reported. Therefore, given reports of discrepancies between subjectively and objectively measured sleep, we explored these

associations in this sample. Specifically, we examined bivariate within-person correlations between the daily subjective sleep outcomes and the daily objective sleep outcomes for survivors and partners in DP1. Bivariate correlations were performed between outcomes tapping like sleep difficulties. That is, we compared self-reported sleep duration with TST, self-reported sleep quality (operationalized as feeling refreshed/rested upon waking) with SE, and lastly, we compared a dichotomous item assessing difficulties with sleep maintenance ("woke up in the middle of the night or early morning when I did not mean to") with number of awakenings. In DP1 at the within-person level, survivors' subjective sleep duration was significantly and positively associated with their TST, but this correlation was small (r = 0.06, p = .038). Partners' subjective sleep duration was significantly and negatively associated with their TST and this correlation was also small (r = -0.11, p = .007). Bivariate correlations between subjective sleep quality and SE as well as between subjective and objective awakenings were not statistically significant, for survivors or partners (all ps ≥ .323). Therefore, while beyond the scope of the current study, daily subjective and objective sleep disturbance were also not strongly correlated in this sample of early-stage BC survivors and their partners.

We are aware of one study that examined the relationship between FCR and objective sleep disturbance. Nelson and colleagues (2018) examined the relationship between global FCR and sleep disturbance assessed via both global retrospective self-report and actigraphy for seven days in hematopoietic cell transplant recipients. FCR was significantly and positively associated with subjective but not mean levels of

objective sleep disturbance (including TST, WASO, and SE). The results of the study by Nelson and colleagues (2018) are therefore in line with the discrepancies found in our own work of couples coping with early-stage BC – FCR is related to greater subjective but not objective sleep disturbance.

Given we previously demonstrated relationships between *global* FCR and average daily subjective sleep disturbance, to further probe the relationship between FCR and objective sleep disturbance we examined the relationship between a latent FCR factor and daily objective sleep disturbance averaged across each 21-day diary period. Although also beyond the scope of the current study, we again did not find significant associations between FCR and objective sleep disturbance (for survivors or partners, actor or cross-partner effects, DP1 or DP2). These results further support the finding of the current study that FCR is not robustly related to objective sleep disturbance.

As previously stated, subjective and objective measures of sleep disturbance have been shown to have unique correlates, including in BC survivors (Dhruva, Paul, et al., 2012). For example, in a study of BC survivors before radiation, fatigue and depression were associated with subjective, but not objective sleep disturbance. In contrast, body mass index, also objective, was shown to be related to objective sleep disturbance. Therefore, the facet of sleep that subjective measures tap may be more related to other subjective variables, such as psychosocial variables like FCR.

Limitations and Future Directions

Limitations of this work should be considered in future work on FCR and objective sleep disturbance. The present study consists of secondary analyses of an intensive longitudinal study that was not specifically designed for the current aims. Following from this, the parent study did not assess the time participants intended to go to sleep in bed at night and the time participants got up out of bed in the morning. These in bed and get up times differ from sleep onset and offset due to the time it takes to fall asleep after one intends to do so and due to lingering in bed after one wakes up, respectively. When compared to the gold standard of polysomnography, actigraphy tends to mistake quiet wakefulness for sleep and can thereby overestimate TST (Pollak et al., 2001). It is therefore recommended that actigraphy have event markers or be coupled with sleep diaries that assess in bed time and get up time and that these times be used to differentiate quiet wakefulness from true sleep (Berger et al., 2008; Buysse et al., 2006; Fekedulegn et al., 2020). These in bed and get up times can also be used to calculate additional objective sleep disturbance parameters, including sleep onset latency (Fekedulegn et al., 2020). Sleep onset latency is defined as the number of minutes it takes to fall asleep (i.e., the number of minutes between the in bed time and sleep onset) and is commonly reported in studies of objective sleep disturbance, including those with BC survivors (Berger et al., 2008; Budhrani et al., 2015; Buysse et al., 2006; Fekedulegn et al., 2020). In the absence of in bed time and get up times, we were unable to examine this parameter. Future research should

examine the relationship between FCR and sleep onset latency because FCR experienced pre-sleep might cause difficulty falling asleep.

Without in bed and get up times, the sleep periods reported in the current study represent the true sleep period (sleep onset – sleep offset interval vs. in bed - get up time interval), TST represents the true sleep minutes (the number of minutes scored as asleep in the true sleep period), and SE represents the percentage of time scored as asleep during the true sleep period (vs. percentage of time scored as asleep during the time in bed; Fekedulegn et al., 2020).

While the current study did not assess in bed time and get up time, participants were instructed to compete the evening diary within one hour of going to bed and the morning diary within one hour of waking. Therefore, we used the diary time stamps to set the night and day intervals to differentiate night sleep periods from any daytime sleep periods. Because these diary completion times are not valid measures for in bed and get up times, sleep onset and offset, as detected by the scoring algorithms, were not hand-edited. Therefore, it is possible that quiet wakefulness was incorrectly scored as sleep, thereby overestimating sleep period length and TST for this sample.

Moreover, actigraphy may especially overestimate TST in populations with elevated levels of sleep disturbance due to quiet wakefulness during difficulty falling or maintaining sleep being incorrectly scored as sleep (Hauri & Wisbey, 1992). Given prior reports of elevated levels of sleep disturbance among BC survivors and partners, it may be especially true then that sleep periods and thereby TST were overestimated in the current study. It is possible that FCR, including worry, rumination, and intrusive

thoughts, experienced pre-sleep causes difficulty falling asleep and that FCR experienced during awakenings causes these awakenings to be prolonged. If these difficulties with sleep onset and maintenance were mistakenly scored as sleep, then overestimation of TST would obscure relationships between FCR and objective sleep disturbance. It is therefore recommended that future studies of FCR and objective sleep disturbance assess for in bed and get up time and use these data to inform actigraphy data processing.

In contrast, there was also some evidence to suggest that sleep period length and TST were *underestimated* on some nights. As described in detail in the Method, the ActiLife software (v6.13.4; ActiGraph, 2019) used the Cole-Kripke algorithm (Cole et al., 1992), which is well-validated for wrist actigraphy, to score each minute as asleep or awake and then the modified Tudor-Locke algorithm (Tudor-Locke et al., 2014) to detect sleep onset and offset. While visualizing and hand-editing the data, we witnessed instances in which the actigraphy data processing methods may have underestimated sleep period length and TST. Specifically, because the Tudor-Locke algorithm uses a minimum sleep period length of 160 minutes, there appeared to be instances in which participants woke up in the night and then returned to sleep, but that this return to sleep was not scored as such due to the period being < 160 minutes. See Supplemental Material S4 for an example. Therefore, it is possible that the Tudor-Locke algorithm underestimated sleep period length and TST, particularly for this sample who is known to have more disturbed sleep, including awakenings and WASO (Budhrani et al., 2015; Chang et al., 2007). However, it is also possible that what

appeared as return to sleep was actually quiet wakefulness and was therefore accurately scored as awake and this anecdotal evidence should be viewed in light of the fact that the actigraphy processing methods used in the current study follow the ActiLife 6 User's Manual (ActiGraph, 2012) as well as prior research using the ActiGraph monitors and ActiLife software for detecting sleep in adult populations (Kreutz et al., 2021; Myllyntausta et al., 2020).

Nevertheless, we explored this possibility by re-processing the actigraphy data but instead applying the Tudor-Locke algorithm with the minimum sleep period length set to a custom value of 20 minutes to allow for possibly shorter sleep periods to be detected. Apart from this change, the actigraphy data processing methods remained the same as those reported in the current study. For example, sleep periods occurring between the evening diary's time stamp and the morning diary's time stamp were combined and coded as the night sleep period. Using these re-processed data, we again did not find significant between- or within-person associations between daily FCR and daily objective sleep disturbance (for survivors or partners, actor or cross-partner effects, in DP1 or DP2), supporting our finding that FCR is not robustly related to objective sleep disturbance in couples coping with early-stage BC.

A major strength of the current study was the collection of daily FCR and continuous assessment of objective sleep, which allowed us to examine the relationships between FCR and objective sleep disturbance at not only the between- but also the within-person level. Apart from our own prior work (Perndorfer et al., 2022), we are aware of no published studies to examine FCR and sleep links at the

within-person level. Within-person analyses assess variables closer in time to when they occur and can therefore capture how processes develop over time (Bolger & Laurenceau, 2013; Hamaker, 2012; Shiffman et al., 2008). Additionally, FCR was assessed in the evening within one hour of going to bed and within-person associations between FCR and objective sleep disturbance controlled for any daytime sleep from earlier that day. Therefore, while the current study is observational in nature, the timing of assessments and ability to examine relationships at the within-person level better get at directionality. While theory supports that FCR negatively impacts sleep, it is possible that instead, after a poor night's sleep, individuals experience more FCR. Indeed, research using ecological momentary assessment has demonstrated that on nights individuals sleep less than is typical for them, they experience greater generalized anxiety the next day (Cox et al., 2018). Therefore, an important future direction for the current work is to examine the lagged, within-person associations between objective sleep disturbance and FCR reported the next day and these analyses could potentially control for FCR reported the previous evening.

It is worth mentioning here that a limitation of actigraphy research more broadly is that actigraphy processing methods vary widely by study, including in studies of cancer survivors (Berger et al., 2008; Fekedulegn et al., 2020). For example, in the current study sleep onset was defined as the first five consecutive minutes of sleep, but definitions for sleep onset range from 1-20 consecutive minutes (Fekedulegn et al., 2020). Moreover, the processing methods used are often not reported, including in studies of cancer survivors, making it difficult to determine the

best methods and compare findings across studies (Berger et al., 2008; Fekedulegn et al., 2020). To address these limitations, a number of recommendations have been published for the use of actigraphy in both research and clinical settings (Berger et al., 2008; Fekedulegn et al., 2020; Morgenthaler et al., 2007). Therefore, as research on objective sleep disturbance in cancer survivors and their partners proliferates, the best practices for processing actigraphy data in this unique population may become clearer.

Rates of objective sleep disturbance in the current sample were compared to the National Sleep Foundation's recommendations for sleep quantity and quality (National Sleep Foundation, 2020; Ohayon et al., 2017). Because sleep in the general population may not meet these recommendations, we also aimed to compare levels of objective sleep disturbance in our sample with estimates for the general population. However, we were surprised to find little published data for actigraphy estimates in a nationally representative sample. Among this little research is a study of objective sleep disturbance in early- and middle-aged adults (Lauderdale et al., 2006) as well as a study of objective sleep disturbance in older adults (Kurina et al., 2015). The study of objective sleep disturbance in early- and middle-aged adults reported actigraphy estimates for four race-sex groups (Lauderdale et al., 2006). The characteristics of the current sample, including age, race, ethnicity, and income, were most similar to the White women and White men subgroups of that study and so we used these subgroups as the comparison samples. However, differences remain between these comparison samples and our own – most notably, the mean ages for the comparison samples were approximately 10 years younger than the mean ages of survivors and partners.

Therefore, this limitation should be kept in mind when interpreting the similarities and differences between objective sleep in our sample and these comparison samples.

While most US adults report sharing the same bed with their intimate partner (National Sleep Foundation, 2012), the current study did not assess whether partners were indeed bed partners or on a daily level, whether they slept together or alone. Couples' sleeping arrangements impact their sleep (Troxel et al., 2007). For example, when co-sleeping, partners demonstrate greater objective sleep disturbance but report greater subjective sleep quality (Troxel et al., 2007). Also, in couples in which one partner is diagnosed with insomnia, awakenings in the diagnosed partner precede awakenings in their non-diagnosed partner (Walters et al., 2020). Therefore, the sleeping arrangements of couples in the current study may have impacted their sleep as well as the relationships between survivors' and partners' objective sleep outcomes. Future studies of objective sleep disturbance in couples coping with BC cancer should assess for couples' sleeping arrangements, including at a daily level.

Lastly, the sample for the current study was homogenous, including with respect to race, ethnicity, and income. Therefore, the results of the current study may not generalize to couples coping with early-stage BC more broadly. Future research should examine levels of objective sleep disturbance as well as relationships between FCR and objective sleep disturbance in more diverse samples of couples coping with BC.

Conclusions

Both BC survivors and their intimate partners demonstrate objective sleep disturbance in the first year post-diagnosis, particularly difficulties with sleep maintenance. Objective sleep disturbance is concordant within-couple, especially so at the time of the first, post-treatment mammogram, which is an important transition in the early survivorship trajectory. Levels of objective sleep disturbance in survivors and partners persist across the first year post-diagnosis. Despite evidence for greater FCR being related to greater subjective sleep disturbance among BC survivors and partners, the results of the current study suggest that FCR is not robustly linked with objective sleep disturbance in couples coping with BC in the first year post-diagnosis.

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Appendix A

OBJECTIVE SLEEP DISTURBANCE OUTCOMES

Sleep period: the number of minutes between sleep onset and sleep offset.

Total sleep time (TST): the number of minutes scored as asleep between sleep onset and offset.

Awakenings: the number of unique awakening episodes between sleep onset and offset.

Wake after sleep onset (WASO): the number of minutes scored as awake between sleep onset and offset.

Sleep efficiency (SE): the quotient of the TST divided by the sleep period length.

Appendix B

DAILY ITEMS FOR SURVIVOR FCR

1. How much time today did you spend thinking about the possibility of cancer recurrence?
   - I didn't think about it at all (0)
   - A few seconds (1)
   - A few minutes (2)
   - A few hours (3)
   - Several hours (4)

Today…

2. I was worried, afraid, or anxious about of the possibility of cancer recurrence.
   Not at all (0) A little bit (1) Somewhat (2) Quite a bit (3) Extremely (4)

3. I was sad, discouraged, or disappointed about the possibility of cancer recurrence.
   Not at all (0) A little bit (1) Somewhat (2) Quite a bit (3) Extremely (4)

4. I was frustrated, angry, or outraged about the possibility of cancer recurrence.
   Not at all (0) A little bit (1) Somewhat (2) Quite a bit (3) Extremely (4)

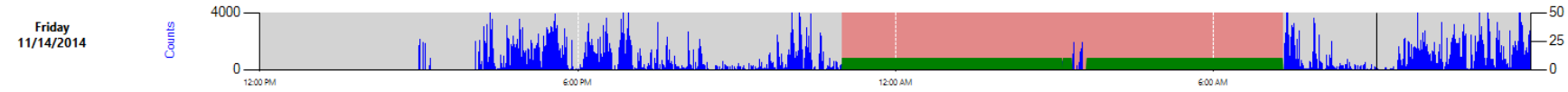
5. I felt helpless or resigned about the possibility of cancer recurrence.
   Not at all (0) A little bit (1) Somewhat (2) Quite a bit (3) Extremely (4)

6. I felt that I worried excessively about the possibility of cancer recurrence.
   Not at all (0) A little bit (1) Somewhat (2) Quite a bit (3) Extremely (4)

Appendix C

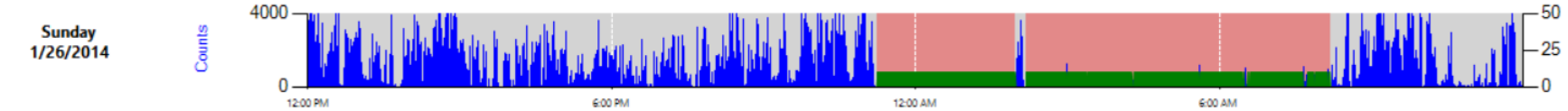
HAND-EDITS TO SLEEP PERIODS

1.



2.

3.

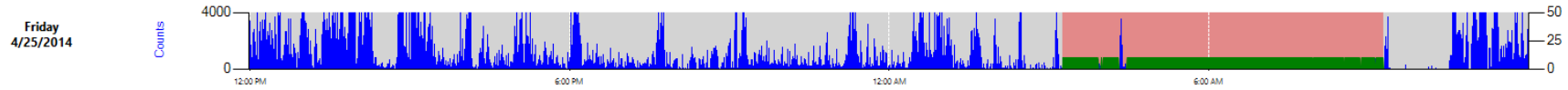


Note. 1. An instance in which sleep was scored between the initialization and the fitting of the accelerometer to the participant (sleep period not shown). In these instances, the sleep period was deleted. 2. An instance in which a non-wear time was scored as sleep (sleep period not shown). In these instances, the sleep period was deleted. 3. An instance in which sleep occurring the same night was scored as multiple sleep periods (sleep periods shown). When these sleep periods

occurred between the evening and morning diary completion time for that participant on that date, the sleep periods were combined and coded as the night sleep period and the sleep outcomes were recalculated for this combined sleep periods.

Appendix D

EXAMPLE OF POTENTIAL MISIDENTIFICATION OF SLEEP AS WAKEFULNESS BY THE TUDOR-LOCKE ALGORITHM



Note. In this example, an awakening occurred at 9:17am, which was coded as sleep offset, thereby ending the sleep period. However, after this awakening, there was a period of low activity (~9:25-10:30am), which may have been incorrectly scored as wakefulness despite the participant having returned to sleep. Without in bed and get up times, we did not edit sleep onset and offset as this period of low activity could also be a period of quiet wakefulness.

Appendix E

IRB/HUMAN SUBJECTS APPROVAL

Institutional Review Board
FWA00006557

Helen F. Graham Cancer Center & Research Institute
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Newark, DE 19713

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MEMORANDUM

Steven Kushner, MD
Chairman, IRB #1
Gary Johnson, PhD
Chairman, IRB #2
Jerry Castellano, Pharm.D, CIP
Corporate Director
Janet Leary-Prowse, MSEd, CIP
IRB Education Specialist
Heidi Derr, BA, CIP
IRB Regulatory Affairs/Auditor
Sonia Martinez-Colon
Executive Assistant
Wendy Bassett
Administrative Assistant
Kelly Crisconi
Administrative Assistant

DATE: September 5, 2017

TO: Jean-Philippe Laurenceau, PhD
Oncology Research
Christiana Hospital

FROM: Wendy Bassett WB

RE: ***CCC# 33026*** - **Surviving Cancer Together: (DDD# 601576)**

This is to officially inform you that the **Closure/Termination** notice for your protocol was reviewed and noted by Jerry Castellano, Pharm.D, CIP, Corporate Director of the Institutional Review Board of Christiana Care Health System, on **09/05/2017.**

The final Continuing Review was also carried out and approved.

If you have any questions or concerns, please contact the IRB Office.

Thank you.