The Smelly Truth: Evidence that Exposure to the Scent of a Romantic Partner Reduces Stress Reactivity and Improves Sleep Efficiency

by

Marlise Kathleen Hofer

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The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

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Examining Committee:

Dr. Mark Schaller, Professor, Psychology Department, UBC
Co-supervisor

Dr. Frances Chen, Associate Professor, Psychology Department, UBC
Co-supervisor

Dr. Elizabeth Dunn, Professor, Psychology Department, UBC
Supervisory Committee Member

Dr. Eli Puterman, Kinesiology Department, UBC
University Examiner

Dr. Daniel Weary, Land and Food Systems, UBC
University Examiner

Abstract

Close contact with loved ones is essential for both mental and physical health. Social support provided by loved ones can reduce stress, improve sleep quality, promote positive health behaviors, and increase resilience to adversity. In everyday life, however, people commonly experience periods of separation from their loved ones. Can the benefits of social support occur even when loved ones are physically distant? The study reported in Chapter 2 collected data from 96 women who were randomly assigned to smell one of three scents (their romantic partner's, a stranger's, or a neutral scent) and exposed to an acute social stressor (Trier Social Stress Test). Perceived stress and cortisol were measured continuously throughout the study. Perceived stress was reduced in women who were exposed to their partner's scent. Cortisol levels were elevated in women who were exposed to a stranger's scent. Cortisol levels were also reduced in women who were exposed to their partner's scent, but only in a subset of women who were able to identify their partner's scent. These results suggest that the scent of a partner improves the psychological experience of stress and improves cortisol levels in a subset of women who correctly identified the scent to be their partner's. The study reported in Chapter 3 collected data from 155 participants who spent two nights with their partner's scent and two nights with a control scent (order randomized). Sleep efficiency (via actigraphy) and perceived sleep quality (via self-report) were measured each night. Sleep efficiency was higher when participants were exposed to their partner's scent. Exposure to a partner's scent led sleep efficiency to increase by over two percent on average, an improvement similar in magnitude to the effect of melatonin on sleep. Perceived sleep quality was higher when participants believed they were smelling their partner's scent. These results suggest that the scent of a partner improves the physiological state of sleep and that believing you are exposed to the scent of your partner improves the psychological recollection of sleep quality. This research adds to our understanding of the role of olfactory cues in the communication of social support.

Lay Summary

This dissertation investigates whether olfactory cues from a romantic partner improve a person's ability to cope with stress and their likelihood of getting a good night's sleep. There are two specific goals. The first goal is to establish whether exposure to the scent of a romantic partner improves psychological and physiological reactions to a laboratory-based stressor. The second goal is to explore whether exposure to the scent of a romantic partner can influence sleep quality outside of the laboratory. By combining two divergent methodologies, I will provide evidence about the role of olfactory cues from a romantic partner on two distinct health-relevant outcomes (stress reactivity and sleep quality) from both a highly-standardized laboratory procedure as well as from a real-life context. The long-term goal of this research is to uncover simple strategies that promote health and can be readily applied across a broad range of situations.

Preface

Parts of Chapter 1 & 4 overlap with a paper currently in press: Hofer, M. K., Chen, F. S. & Schaller, M. (2020). What Your Nose Knows: Affective, Cognitive, and Behavioral Responses to the Scent of Another Person. *Current Directions in Psychological Science.* I am the primary author of this review paper, with contributions from F. S. Chen & M. Schaller.

A copyedited version of Chapter 2 has been published: Hofer, M. K., Collins, H., Whillans, A., & Chen, F. (2018). Olfactory Cues from Romantic Partners and Strangers Moderate Women's Stress Responses. *Journal of Personality and Social Psychology*, 114, 1-9. I am the primary author of this work: I identified and designed the research program, supervised data collection, conducted data analyses, and drafted the manuscript. F. S. Chen contributed to study design and data interpretation. H. Collins collected data and helped with manuscript preparation. All authors edited the manuscript.

A copyedited version of Chapter 3 has been published: Hofer, M. K., & Chen, F. S. (2020). The Scent of a Good Night's Sleep: Olfactory Cues of a Romantic Partner Increase Sleep Efficiency. *Psychological Science.* I am the primary author of this work: I designed the studies, supervised data collection, conducted data analyses, and drafted the manuscript. F. S. Chen contributed to identification and design of the research, data interpretation, and edited the manuscript.

The research presented in this dissertation was approved by UBC Behavioral Research Ethics Board, UBC BREB Number: H14-01217.

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List of Abbreviations

95% CI – 95% Confidence Interval

ANOVA – Analysis of Variance

b – Unstandardized regression coefficient

d – Cohen's D

FE - Fixed effects

ICC – Intraclass Correlation Coefficient

HLM – Hierarchical Linear Model

M – Mean

MLM – Multilevel Modeling

N – Sample size when discussing the entire sample

n – Sample size when discussing a subset of the sample

p – p-value

SD – Standard Deviation

SE – Standard error

SEM – Standard Error of the Mean

TSST – Trier Social Stress Test

Z – Z score

Glossary

Actigraphy monitors / Actiwatch – wrist-worn devices similar to a smartwatch that record motor activity and use an algorithm to distinguish sleep from wakefulness.

Sleep efficiency - calculated by dividing time asleep over total time spent trying to fall asleep. It represents the proportion of time a participant spends asleep out of the total time they spend attempting to sleep.

Trier social stress test (TSST) - standardized in-lab procedure to induce moderate to acute social-evaluative stress. Participants engage in a speech and unanticipated math task in front of two judges. Judges are trained to appear neutral throughout the stress procedure and avoid smiling, nodding, and non-verbal feedback. Procedure is conducted according to the original protocol (Kirschbaum et al., 1993).

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Which brings me to my son, Kai, who has actually made graduating harder, but has also added an immense amount of cuteness to my life. Finally, and most importantly, I could never have completed this degree without the daily cup of coffee provided by my wonderful partner, Kevin.

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Dedication

I dedicate this dissertation to my parents: Dr. Kurt G. Hofer and Maria G. Hofer. Your support has been unshakable throughout my education (an life!) and I would not be where I am today without everything you have done for me. I love you both very much and I hope I can provide the same level of support and love to Kai that I have always received from you.

Chapter 1: Introduction

People smell. Every person emits a body odor which lingers even when the person is not physically present. People smell other people. Although humans are often considered the olfactory dunces of the animal kingdom, we actually have a highly-developed olfactory system that discriminates between a wide range of scents—including odors of other people (McGann, 2017). Those odors inform inferences about those other people and about the situations in which the odors are encountered. Several lines of research reveal how body odors of strangers affect perceivers' emotional responses as well as their impressions of those strangers. In this dissertation I examine how body odors of familiar people—romantic relationship partners—influence perceivers' health relevant outcomes. Specifically, I demonstrate how the lingering smell of a romantic partner tacitly connotes their presence, with implications for stress reduction and sleep enhancement.

In this introductory chapter, I will review the human olfactory system and discuss the process by which people learn to associate body odors with different kinds of interpersonally-relevant information, with implications for affective, cognitive, and behavioral responses (see Table 1). I will then summarize research on the inferences that people draw from body odors—including inferences about their transient emotional states, as well as more enduring personal characteristics. Finally, I will discuss the psychological consequences of smelling a familiar body odor within the context of attachment theory. I will conclude by outlining the goals of the data collected for this dissertation.

1.1 Body Odors as Social Signals

Until recently, scent communication was largely overlooked within psychological research due to a general belief that humans have a feeble sense of smell. However, this assumption is untrue; in fact, humans can detect certain odors at concentrations equivalent to three droplets in an Olympic pool, and humans share the ability of super-smelling animals (such as rats and dogs) to track a scent trail through a field (de Groot, Semin & Smeets, 2017). In short, human scent sensitivity does not appear to be inferior to other animals, but instead scent sensitivity to *specific odors* varies significantly between species, likely in line with survival needs (see McGann, 2017 for a review).

In many animals, two distinct olfactory systems exist: the main and the accessory system. The accessory olfactory system detects stimuli via the vomeronasal organ, an organ that is thought to be nonfunctional in humans (McGann, 2017). Since the accessory olfactory system plays a large role in social odor communication in some animals, the lack of a functional vomeronasal organ led some researchers to believe social scent communication did not exist in humans. However, over the past decade evidence has accrued that the main olfactory system can also detect odors from conspecifics (Baum & Cherry, 2015), and it is now widely accepted that humans can communicate socially via odor.

While the human ability to communicate via scent is no longer disputed, the importance of social olfactory signals in daily life remains unknown. It may be possible to gain some insights about the importance of scent for humans by examining people who do not have a sense of smell, a condition known as anosmia. If the sense of smell plays an important role human communication, we may expect its absence to negatively impact social functioning. In line with this idea, people with anosmia report having fewer social interactions, lower sexual satisfaction, and decreased feelings of security in their current romantic relationship (Boesveldt, Yee, McClintock, & Lundström, 2017; Croy, Bojanowski, & Hummel, 2013). These results are consistent with the idea that the sense of smell is a critical ingredient in social relationships.

Given the importance of scents in social communication, a natural question is whether these scents qualify as "pheromones." This question still sparks debate amongst scholars largely because there is no consensus as to the exact definition of the term "pheromone" (Doty, 2010; Wyatt, 2014). One widely cited definition is that pheromones are species-wide chemical signals (Wyatt, 2014), a definition that largely excludes learned olfactory signals. It is unlikely that humans have fully innate responses to social odors (Doty, 2010), with the potential exception of a breast odor that may elicit search and suckling behavior in newborns; Schaal & Al Ain, 2014). Individual and cultural factors form a critical part of our reaction to an odor (Stevenson, 2010). For example, some foods—such as Chinese stinky tofu—are treasured in one culture but leave outsiders disgusted. Due to the difficulty in disentangling cultural versus biological factors, and the confusion about the precise definition of the term "pheromone", I choose to avoid the term altogether and instead discuss social olfactory signals.

Table 1.1 Three categories of learned associations with body odor, and some of their psychological consequences

Olfactory associations between	Psychological consequences of exposure to olfactory cue	Illustrative research example
Body odors and transient emotional states	Tacit inferences about other individuals' emotional states Emotion-congruent appraisals of one's environment; responses reflecting those appraisals	The scent of a fearful person enhances perceivers' own anxiety and propensity to trust others (Quintana et al., 2019)
Body odors and personal characteristics	Tacit inferences about other individuals' personal characteristics Interpersonal judgments; decisions reflecting those judgments	The scent of a sick person leads to decreased liking (Regenbogen et al., 2017)
Body odors and presence of a specific individual of special relevance to self	Tacit inferences about presence of a specific person Appraisals of and responses to one's environment consistent with the presence of that specific person	The scent of a mother's milk facilitates transition from feeding tubes to oral feeding in preterm infants (Yildiz, Arikan, Gözüm, Taştekın & Budancamanak, 2011)

In order for body odor to serve as a social signal, a body odor produced by one person must transmit a message to another person (Wyatt, 2014). People experiencing a specific state or possessing a particular trait may produce a sufficiently distinctive chemical profile; this chemical profile may then be repeatedly perceived in specific contexts (e.g., perception of a fear odor in fear-inducing contexts). Over time, the recurrent pairing of the distinctive chemical profile and the specific context can forge a learned association between the two (de Groot, Semin & Smeets, 2017). Table 1.1 summarizes three categories of learned associations with body odor, and their implications.

1.2 Associations Between Body Odors and Transient Emotional States

Social scents can impact how we appraise our surroundings. If people around us are experiencing a strong emotion, this emotion may be a response to a functionally-relevant event (e.g., threat or opportunity) in the environment that may be relevant not only for the person experiencing the emotion, but also other people in their immediate environment. The experience of an emotion is associated with distinctive physiological changes in the body, which may affect body odor (Kadohisa, 2013). Therefore, just as perceivers can infer someone's emotional state from viewing their facial expressions (Shariff & Tracy, 2011), perceivers may also infer someone's emotional state from their body odor (de Groot, Semin & Smeets, 2017). These inferences can guide how perceivers respond to these individuals and their shared environment.

The smell of fear may be especially relevant to perceivers because it connotes potential danger. Accordingly, olfactory communication of fear has been documented in many studies (for a review, see de Groot & Smeets, 2017). In many of these studies, people watched either a neutral or fear-inducing film clip while their body odors were collected on an absorbent material.

Later, when new participants smelled the material collected from fearful people, they too exhibited responses consistent with fearfulness, such as a pronounced startle reflex in response to a loud noise, spontaneously fearful facial expressions, and greater subjective anxiety (de Groot et al. 2012; Albrecht et al. 2011). For example, in one study, people interacted with a virtual character while smelling body odor collected from either a fearful person or a non-fearful person; those smelling the fearful odor experienced greater anxiety themselves and were less trusting of the virtual character (Quintana, Nolet, Baus & Bouchard, 2019). A recent meta-analysis combined results from twenty-six studies of humans communicating fear, stress, or anxiety via body odor and found robust evidence for the human capacity to perceive and react to these odor signals (de Groot & Smeets, 2017).

Happiness signaling arguably carries less evolutionary importance than fear signaling, and has received much less attention in the scent signaling literature. However, what little work has been done in this area supports the idea that happiness may be transmitted via scent. Two studies found that female participants were able to identify the odor of happy people compared to fearful and control odors at above chance levels (Chen and Haviland-Jones, 2000; Zhou & Chen, 2011). Another study found that exposure to the sweat produced by happy people elicited happier facial expressions in perceivers (de Groot et al., 2015).

The ability to detect the presence of anger or aggression in another individual could constitute an important survival benefit, as it allows for preparation for or avoidance of a potentially dangerous situation. Scent cues may be one way we identify anger and aggression in others, and once again work in this area appears to support this possibility (though evidence is quite limited). One study found that self-rated dominance was detectable via scent cues left in worn shirts (Sorokowska, 2013). In addition, smelling scents collected during competitive and aggressive situations led perceivers to experience increased arousal and impaired cognitive processing (in line with anxiety reactions; Mutic et al., 2016; Adolf et al., 2010).

The emotion of disgust may also be communicated via scent. One study exposed participants to armpit odors produced by people experiencing either fear or disgust (induced by viewing a film clip; de Groot et al., 2012). Exposure to disgust odors caused perceivers to wrinkle their noses and make fewer eye fixations (an indicator of sensory rejection). In contrast, exposure to fear odors elicited eyebrow raising and increased vigilance (indicators of anxiety; de Groot et al., 2012). Taken together, there is strong evidence in the literature for the communication of fear via body odor, and several other emotions (including happiness, anger/aggression, and disgust) may also be communicated via scent, but research on these emotions is still quite limited.

The experience of certain emotions can also influence our scent sensitivity. Some emotional states (such as disgust and fear) occur when we perceive potential dangers. Experiencing these emotions may facilitate the acquisition of olfactory information, such as disgusting smells (e.g. food spoilage) or fear-inducing smells (e.g. smoke). Indeed, research indicates that people experiencing both fear and disgust have an increased sensitivity to scents, meaning that they can detect scents at a lower threshold (Chan et al., 2016; Chan, Dooren, Holland & Knippenberg; 2019). In contrast, the experience of another negatively-valanced emotion, sadness, has the opposite effect on smell sensitivity (reduced ability to detect scents; Schablitzky & Pause, 2014).

1.3 Associations Between Body Odors and Personal Characteristics

People engage in many different interactions with many different people, and they calibrate these interactions in a discriminatory way: they avoid interactions with people who pose threats and seek interactions with other people who offer rewards (potential friendship, potentially fruitful mating opportunities). The costs and benefits of a given interaction depends on the characteristics of potential interaction partners, including enduring traits (e.g., the individual's sex, genetic fitness) as well as more transitory states (e.g., sickness, sexual interest).

A person's body odor contains information that can help perceivers identify some of these characteristics. For example, using cues from odor alone, perceivers can infer a variety of functionally-relevant demographic characteristics (Semin & De Groot, 2013). Sex can be correctly classified from odor samples with 75% accuracy (Penn et al., 2007), which may be partially due to the fact that body odor samples from men are generally rated as stronger and less pleasant than those from women (Sorokowska et al., 2012). Age can also be inferred via body odor. Estimates of age (based on odor samples) are positively correlated to actual age (Sorokowska et al., 2012), and participants can discriminate odor samples from older individuals (75 and over) compared to younger individuals at levels greater than chance (Mitro et al, 2012).

In the domain of mating, scent is rated to be one of the most important determinants in assessing a potential mate (e.g. Herz & Inzlicht 2002). Pioneering research found that people rate another person's body odor as sexier when the odor was produced by a person with a genetically dissimilar immune related gene profile, a preference with is thought to facilitate the avoidance of inbreeding (Wedekind & Furi, 1997; however see Havlicek & Roberts, 2009 for a review which finds mixed evidence for this effect).

Body odor may also provide clues about another person's potential receptivity to a mating relationship (e.g., sexual arousal; Wisman & Shrira, in press), and to traits or states that might make them more desirable mating partners. For instance, throughout much of human history, a woman's desirability as a mate is likely to have been influenced, in part, by her capacity to conceive a child. One consequence is that men may be sensitive to body odors that are associated with a woman's likelihood of conception (Haselton & Gildersleeve, 2016). Consistent with this theory, when women have a higher likelihood of conception (e.g., during ovulation, compared to other phases of the menstrual cycle), their scents are judged by men to be more pleasant and sexually attractive, and exposure to these scents stimulates higher levels of male sexual arousal and testosterone (Hoffmann, 2019; Gildersleeve, Haselton, Larson & Pillsworth, 2012; Miller & Maner, 2010; Cerda-Molina et al., 2013).

A woman's potential to conceive may also affect her own scent-based inferences about potential mates. It has been hypothesized that, when conception risk is higher, women will be more highly attuned to male characteristics that, historically, were associated with greater reproductive fitness (e.g. symmetrical features, dominance; Gildersleeve, Haselton, & Fales, 2014). Some of these characteristics may also be associated with distinctive body odors. In line with this analysis, near ovulation when women's conception risk is higher, women prefer scents from men with more symmetrical features, higher dominance, and higher testosterone levels (Thornhill, Chapman & Gangestad, 2013; Havlicek, Roberts, & Flegr, 2005). These findings indicate that when conception risk is highest, women favor scents from men who possess features that would be advantageous for potential offspring. However, there is ongoing debate on this topic (e.g. see Wood, Kressel, Joshi, & Louie, 2014, who conclude that women's preferences do not change across the ovulatory cycle). Research using larger samples and more precise fertility measurement will be necessary for clarity to be reached on this issue.

Body odors can also provide information about whether another person poses a threat of some kind—such as the threat posed by an infectious disease. Interacting with someone with an infectious disease can be dangerous and potentially fatal. Thus, identification of cues indicating potential sources of disease facilitates cognitive and emotional responses that invoke avoidance of an individual deemed to be an infection risk (Schaller & Park, 2011). Many diseases are associated with changes in body odor (Shirasu & Touhara, 2011); just as other animals use olfactory cues to identify and avoid infected individuals (e.g., Kavaliers, Choleris & Pfaff, 2005), humans too appear to be able to infer illness from body odor (Olsson et al., 2014). Several studies have used a clever paradigm to examine the scent of sickness: inflammatory responses are experimentally induced in otherwise healthy adults by injecting them with an endotoxin which reliably provokes a sickness response (Regenbogen et al., 2017). Scent samples are collected twice, once after the endotoxin injection and again after a placebo injection. Scents from “sick” individuals are rated to be more aversive and judged to come from less healthy individuals (Sundelin et al., 2015). In addition, participants rate others as less likable during exposure to the sickness scent (Regenbogen et al., 2017; Sarolidou et al., in press). Reduced liking of others during the perception of olfactory sickness cues may motivate avoidance of people carrying infectious diseases, indicating that social olfactory signals support our behavioral defenses against disease.

1.4 Associations Between Body Odor and Presence of a Loved One

The research reviewed so far involved information learned from the scent of a stranger, while the data I will present in this dissertation examines reactions to a familiar person's body odor. What happens when we come into contact with a scent of someone we already know? Because each individual has a unique body odor that remains relatively stable over different days (Kuhn & Natsch, 2009), once a particular odor is associated with a particular person—such as a lover, friend or family member—the odor can be used to infer that individual's identity (Hold & Schleidt 1977; Lundström, Boyle, Zatorre, & Jones-Gotman, 2008; Lundström & Olsson, 2010). Once a scent is recognized as belonging to someone we know, it is no longer necessary to predict that person's age, sex, and attractiveness. Familiar social scents may be functional in a different way, in that they provide tacit evidence of that person's current or recent physical presence, which could have downstream consequences for the perceiver. The nature of these downstream consequences is likely to be contingent upon the type and strength of the relationship between the two parties.

1.4.1 Parent-Child Attachment

One particularly close social relationship is the attachment between a parent and their child. Infants are born immature and can only survive if they form an attachment with an adult who is willing to protect and provide for them. Attachment theory posits that resulting selection pressures led infants to evolve a set of attachment behaviors which facilitate close proximity to their caregiver (e.g. crying, smiling, following; Bowlby, 1982). When young children are in close proximity to their attachment figure, they are afforded a sense of emotional security, more effective day-to-day functioning, and improved physiological and psychological regulation (e.g., Ainsworth, Blehar, Waters, & Wall, 1978; Larson, Gunnar, & Hertsgaard, 1991). Proximity to an attachment figure is especially likely to be sought when an infant is distressed, as a parent serves as a safe haven. Parents also represent a secure base from which infants can safely explore the world.

Over repeated interactions with their caregiver, children are believed to develop a set of mental representations (or internal working models) that are based on past interactions with their caregiver (e.g., Johnson, Dweck & Chen, 2007; Gunaydin, Zayas, Selcuk, & Hazan, 2012). If caregivers are typically caring and responsive, the child learns that their caregivers can be counted on when needed. For example, in the context of fear or distress, repeated availability of the caregiver for comfort can reinforce an association between the caregiver, stress reduction, and safety. Over time these mental representations can be activated even when the caregiver is not physically present. For example, children can find solace in the fact the caregiver could be contacted if needed (Ainsworth et al., 1978). In this way, cues and reminders of a caregiver can induce the psychological and physiological states of safety and comfort that were initially created during physical interactions with that person (e.g., Depue & Morrone-Strupinsky, 2005; Selcuk, Zayas, Günaydin, Hazan & Kross, 2012). The scent of a caregiver may serve as one such cue.

Mothers and children are able to identify one another via scent, with mothers learning the scent of their newborn very quickly (Russel, Mendelson & Peeke, 1983). In one study, mothers were asked to smell three shirts (one of which had been worn by their newborn) and identify their newborn’s shirt. Mothers who had spent less than ten minutes with their newborn were not able to identify the correct shirt above chance; however, those who had spent at least ten minutes with their newborn were able to make an accurate identification 90% of the time, and mothers who had spent over an hour with their newborn were able to make an accurate identification 100% of the time (Kaitz, Good, Rokem & Eidelman, 1987). Mothers also find their babies' odors pleasant, and the mere scent of a baby activates reward-related areas in the mother's brain (Croy, Frackowiak, Hummel & Sorokowska, 2017; Lundström et al., 2013).

Reciprocally, babies can also identify their mother by scent (Russel, 1976; Schaal et al., 1998) and use scent cues to crawl to their mother's chest to feed, a behavior that does not occur when the mother's scent is masked (Varendi, Porter & Winberg, 2001). Babies also benefit when they smell their mothers. In one study, preterm infants who were exposed to the odor of their mother's breast milk consequently transitioned more quickly from feeding tubes to oral feeding and were discharged from hospital an average of four days sooner than babies exposed to no odor (Yildiz, Arikan, Gözüm, Taştekın & Budancamanak, 2011). Other studies show that infants who smelled their mother's breast milk (compared to control scents such as water or formula) during a briefly painful event (a blood draw from their foot) displayed reduced pain reactions, lower heart rates, and lower cortisol responses—indicating that infants find the mere scent of their mother comforting (Akcan & Polat, 2016; Badiee, Asghari & Mohammadizadeh, 2013; Nishitani et al., 2009).

1.4.2 Romantic Partner Attachment

Like infants, adults also form attachments to others and find these people calming. In adulthood, romantic partners are often the main attachment figure (DeLongis & Holtzman, 2005; Zeifman & Hazan, 2016). Attachments between adults share important differences to those involving infants. The largest difference is that childhood attachment operates largely in one direction: care is given by the adult and received by the child. Adult attachment relationships are bidirectional, with both members of the couple sometimes receiving and giving care.

Noteworthy similarities also exist between parental and romantic attachments. For example, both relationships involve close physical contact (e.g., sex, breastfeeding), baby talk, and the sharing of exciting “discoveries” and experiences (Fraley & Shaver, 2000). In addition, just like infants, adults are comforted when their attachment figure is present, and a romantic partner can serve as a secure base to help their partner face surprises, opportunities, and challenges as well as a safe haven where a distressed partner can retreat for reassurance and comfort. Indeed, research indicates that a romantic partner is usually the first person contacted in times of stress (Coyne & DeLongis, 1986), and the physical presence of a romantic partner can buffer stress reactions (Ditzen et al., 2007) as well as improve sleep (Diamond, Hicks, Otter-Henderson, 2008). Can the mere scent of a romantic partner also create these beneficial outcomes?

Romantic partners are aware of each other’s scents, and find each other’s scents to be pleasant and comforting (Porter & Moore, 1981; Hold & Schleidt, 1977; McBurney, Shoup, & Streeter, 2006). One initial study examined effects of the scent of a partner and found that perceptions of stress were lower in people smelling their partner’s scent compared to those smelling no scent or a stranger’s scent (Streeter, 2009). In this dissertation I will explore whether the mere smell of a romantic partner leads to psychological and physiological improvements in health-relevant outcomes.

1.5 Health Outcomes Examined

Stress is increasingly becoming recognized as an important public health concern; a 2007 national survey by the American Psychological Association (APA) reports that one third of Americans are living with severe stress. High levels of stress are associated with decreased health, shorter life expectancy and poorer sleep quality (Lantz, House, Mero & Williams 2005). For example, over 70% of Americans reported experiencing physical or psychological symptoms related to stress within the last month and almost half report lying awake at night due to stress at least once in the past month. Stress is also associated with unhealthy behaviors: 43% of Americans report coping with stress by overeating, eating unhealthy foods, and many also reported increased drinking and smoking during periods of high stress (APA, 2007). Research aimed at everyday methods of reducing stress could inform future interventions to combat these health concerns.

A number of studies have established that high levels of stress and rumination negatively impact sleep quality, whereas increased perceptions of social support improve sleep quality (Felder, Epel, Coccia, Puterman & Prather, 2018; Akerstedt, Knutsson et al., 2002; Jacquinet-Salord et al., 1993; Cacioppo & Hawkley, 2003; Friedman et al., 2005). The spontaneous behavior of many adults (sleeping with absent partner's clothing or on their side of the bed) is consistent with the possibility that the scent of a loved one may help regulate sleep. Thus, sleep may provide a promising naturalistic context in which to investigate whether olfactory cues may influence health-relevant outcomes.

Sleep deprivation is caused by a variety of factors including inefficient sleep or an inability to fall or stay asleep. Sleep disorders affect an estimated fifty to seventy million (NHLBI, 2003), and the negative public health consequences of sleep loss and sleep-related disorders are substantial. Individuals with chronic sleep loss (compared to healthy individuals) are less productive, require above-average expenditure on health care, and have higher likelihood of injuring themselves and others through accidents (CNTS, 1996). Sleep deprivation has also been associated with increased mortality as well as several of the leading causes of death including cancer, Alzheimer's and diabetes (Knutson, Spiegel, Penev & Cauter, 2007; Grandner, Hale, Moore & Patel, 2010; Heslop, Smith, Metcalfe, Macleod & Hart, 2002). Research aimed at practical methods of increasing sleep efficiency may have direct practical relevance to the broader public.

1.6 Goals

The primary purpose of this dissertation is to investigate the role of olfactory cues of romantic partners on adults' effectiveness in coping with stress and having a good night's sleep. The dissertation has two specific goals. **Goal 1** (addressed in Chapter 2) is to replicate and extend Streeter's 2009 study by examining whether psychological and physiological reactions to a laboratory-based acute stressor are influenced by exposure to the scent of a romantic partner. **Goal 2** (addressed in Chapter 3) is to explore whether exposure to the scent of a romantic partner can influence sleep quality outside of the laboratory.

Chapter 2: Olfactory Cues from Romantic Partners and Strangers Moderate Women's Responses to Stress

2.1 Short Summary

The scent of another person can activate memories, trigger emotions, and spark romantic attraction; however, very little is known about whether and how human scents influence responses to stress. In the current study, ninety-six women were randomly assigned to smell one of three scents (their romantic partner's, a stranger's, or a neutral scent) and exposed to an acute stressor (Trier Social Stress Test). Perceived stress and cortisol were measured continuously throughout the study (five & seven times, respectively). Perceived stress was reduced in women who were exposed to their partner's scent. This reduction was observed during stress anticipation and stress recovery. Cortisol levels were elevated in women who were exposed to a stranger's scent. This elevation was observed throughout stress anticipation, peak stress, and stress recovery. The current work speaks to the critical role of human olfactory cues in social communication and reveals that social scents can impact both psychological and physiological reactions to stress.

2.2 Introduction

People regularly rely on social partners for support during stressful situations (DeLongis & Holtzman, 2005). Contact with social partners has a multitude of positive influences on mental and physical well-being (Uchino, Cacioppo & Kiecolt-Glaser, 1996; Eisenberger, Taylor, Gable, Hilmert & Lieberman, 2007; Heinrichs, Baumgartner, Kirschbaum & Ehlert, 2003; Uchino &

Garvey, 1997). Meta-analyses suggest that positive effects of social support on health are comparable to—or even larger than—positive effects of exercise, weight control, and not smoking (Holt-Lunstad, Smith, Baker, Harris & Stephenson, 2015; Holt-Lunstad, Smith & Layton, 2010).

A romantic partner is often the first person we turn to in times of stress (Coyne & DeLongis, 1986), and research suggests that support from a romantic partner can buffer the negative effects of stress on well-being (Bodenmann, Meuwly & Kayser, 2011; Dehle, Larsen & Landers, 2001). For example, physical contact with a romantic partner—including holding hands and receiving a massage (Coan, Schaefer & Davidson, 2006; Ditzen et al., 2007)—is an effective and reliable buffer of physiological and psychological responses to stress. Some of the benefits of a supportive other can be realized through activating a mental representation of that person. For example, after a painful experience, viewing a photograph of a romantic partner reduces emotional and self-reported pain (Selcuk, Zayas, Günaydin, Hazan & Kross, 2012; Eisenberger et al., 2011; Younger, Aron, Parke, Chatterjee & Mackey, 2010).

It is less clear whether, or under what specific conditions, strangers might have a similar stress-buffering effect. One study reported that holding hands with a stranger during a stressful experience buffered threat responses (Coan, Schaefer & Davidson, 2006). However, a follow-up study with a larger and more representative sample did not find a similar stress-buffering effect of strangers (Coan et al., 2017). Two further studies exposing participants to painful stimuli also found no evidence for a stress-buffering effect of strangers (Eisenberger et al., 2011; Master et al., 2009). One potential explanation for these divergent findings is that people’s reactions to a stranger may depend heavily on the social context, traits (social anxiety, attachment styles), and socioeconomic status (SES). For example, low SES has been associated with higher levels of perceived threat to ambiguous social stimuli, suggesting that lower SES individuals might reap fewer benefits from interactions with strangers (Chen & Paterson, 2006).

Compared to what is known about visual (photos) and tactile (hand-holding) modalities, far less is known about the effects of human scents on stress responses. Research shows that the scent of a loved one can be identified and is considered both pleasant and comforting (Porter & Moore, 1981; Hold & Schleidt, 1977; Shoup, Streeter & McBurney, 2008). Indeed, one study indicated that over 80% of female and 50% of male undergraduates intentionally smell their partner’s worn clothing (McBurney, Shoup & Streeter, 2006). These actions led to feelings of comfort and relaxation (43% for females and 16% for males), and/or security and safety (10% for both sexes), suggesting that exposure to a partner’s scent may incur immediate psychological benefits.

In line with this reasoning, one study asked people to bring to the lab a shirt that had been previously worn by their romantic partner (Streeter, 2009). Participants were then blindfolded and exposed to the scent of either their partner, a stranger, or an unworn shirt directly following a stressful mock interview. Results indicated that participants felt less stressed when they smelled their partner’s shirt compared to the control scents.

The smell of a loved one may be more than just psychologically comforting; it may also have effects on physiological responses to stress. Cross-species research provides initial support for this possibility. For example, rats—like humans—exhibit a reduced cortisol response to stressors while in the presence of a familiar rat. However, olfactory cues are essential for this social stress-buffering effect in rats to appear: when a stressed rat is unable to smell a familiar other, the stress-buffering benefit on cortisol levels is lost (Kiyokawa, Takeuchi, Nishihara & Mori, 2009). Studies on human infants have documented that newborns are calmed by the scent of their mother's milk, an effect that manifests itself in reduced movement and decreased cortisol levels of the infant (Nishitani et al., 2009; Rattaz, Goubet & Bullinger, 2005). However, to our knowledge, there is no empirical research exploring whether and how olfactory cues of supportive others influence responses to stress in adult humans.

It is also unknown whether and how olfactory cues of strangers' influence responses to stress. One study found that exposure to a stranger's scent was consistently rated as more intense and less pleasant than a friend's scent, and that a stranger's scent activated cortical regions associated with viewing threatening stimuli (such as photos of people displaying fearful facial expressions; Lundström, Boyle, Zatorre & Jones-Gotman, 2007). Thus, it is possible that detecting a stranger's scent may be a unique signal of physical proximity to a potentially dangerous individual, triggering increased perceived stress and/or mobilizing the body's physical resources for an uncertain event. This mobilization could activate the hypothalamic–pituitary–adrenal (HPA) axis, resulting in elevated cortisol levels (Jacobson, 2005).

In order to examine these possibilities, we randomly assigned women to smell one of three shirts (their romantic partner's, a stranger's, or an unworn shirt), after which they underwent a stressful lab event (Trier Social Stress Test [TSST]; Kirschbaum, Pirke & Hellhammer, 1993). Their stress responses (perceived stress and cortisol[1]) were monitored throughout the procedure. These results will provide an important replication of the results found in Streeter (2009), as well as build on the findings in that study. We predict that, as in Streeter (2009), the scent of a romantic partner will buffer psychological stress reactions. Additionally,

[1] Heart rate data was also collected using POLAR chest straps and watches worn by the participants during the procedure. However, due to equipment malfunction, over a fourth of our data was lost. Even the remaining data were unreliable often with small segments of missing data. Analysis on the reduced dataset (available in supplemental material) resulted in no significant effects of condition.

we predict that physiological stress reactivity (indexed by salivary cortisol) will also be buffered by exposure to the scent of a partner. Our study design offers more experimental control than Streeter (2009) due to our standardized scent collection procedures, standardized scent age, exclusions for medications known to influence stress reactivity, testing done in a single phase (luteal) of women's menstrual cycle, three month minimum relationship length, fully double-blind experimental design, and validated and more acute laboratory stressor. In addition, our study included multiple scent exposure occasions before, during, and after stress induction (compared to one scent exposure), as well as multiple stress measurements occasions (compared to one measurement done after scent exposure).

Our hypothesis and design, but not our data analysis plan, were preregistered through the Open Science Framework (https://osf.io/vzbrd/). Due to the lack of a preregistered analysis plan, all analyses reported in this chapter should be considered exploratory rather than confirmatory. We did not make a directional prediction regarding how reactions to the stranger's scent will compare to the unworn scent. We encountered unexpected difficulty recruiting couples, so we established a (non-preregistered) stopping rule to terminate recruitment after 2.5 years (thirty months) of data collection if the target sample of 150 couples had not been reached. Data was not analyzed, and cortisol was not assayed, until the final sample was reached. The final sample included ninety-six couples. Due to the reduction in power associated with the reduced sample size, we did not examine individual differences in the effectiveness of the scent manipulation as originally planned. This preregistration represented my first attempt to preregister a study, and, in retrospect, is lacking some important elements (most notably an analysis plan). In a recent paper on researcher degrees of freedom, Wicherts and colleagues (2016) outline 34 degrees of freedom available to researchers, 9 of which are in the hypothesis and design phase, and 15 of which are in the analysis phase. My preregistration can offer some additional confidence about the former phases but should not be seen as offering any confidence about the latter phase.

2.3 Materials and Methods

2.3.1 Participants

Ninety-six couples completed the study (mean female age 21.5 years, *SD* 4.06; mean male age 22.8 years, *SD* 5.29; relationship mean length 2.4 years, *SD* 2.2). Participants primarily identified as Asian (including South Asian and Indian, 74%), or Caucasian (22%). The remaining 4% of participants identified as a variety of other ethnicities (e.g., Black, Arab).[2] Participants were eligible to complete the study if they were in heterosexual long-term romantic relationships (> 3 months) and met basic health and screening criteria (e.g., no chronic medical disorders, had the ability to smell). Given the influence of sex hormones on cortisol reactivity, and olfactory sensitivity (Kirschbaum, Kudielka, Gaab, Schommer & Hellhammer, 1999; Lundström, McClintock & Olsson, 2005), women currently using hormonal birth control were ineligible to participate in the study. Methods were approved by the university's behavioral research ethics board. See Supplemental Table A.2 for more detailed information about recruitment, eligibility, and exclusions.

[2] Differences across groups was not statistically tested due to sample size constraints; however, exploratory analyses suggested no obvious differences by ethnicity.

2.3.1.1 Scent Donors.

Female participants' male romantic partners acted as the "scent donors" and produced the scents used by the women in the partner and stranger conditions (i.e., women exposed to a stranger's scent smelled a shirt from another woman's partner). The male partners of all women were asked to follow the same scent collection procedures so that all couples had the same experience (even though not all shirts were actually used because some women were randomly assigned to the "no scent" control condition). In order to capture natural body odor, we provided each male scent donor with a white T-shirt which they wore for twenty-four hours. Recent research indicates that body odors presented on worn t-shirts are perceived similarly to body odors in live interactions (Gaby & Zayas, 2017). Scent donors followed procedures consistent with standard data collection methods (Miller & Maner, 2010; Singh & Bronstad, 2001). Specifically, to reduce extraneous odors, scent donors were instructed to shower with unscented soap and shampoo (provided by us), refrain from using deodorant or scented body products, sleep alone, and avoid activities such as exercise, drinking, smoking or eating odor-producing foods (e.g. garlic, onion, vinegar). They were also asked to use unscented laundry detergent (provided by us) to wash bed linens and clothing that would come into contact with their shirt.

Men were given minimal information about the purpose of the experiment; specifically, upon arrival they were informed that the study was "looking at the role of smell" and that in order for us to obtain accurate results, it was important that they ensure that the t-shirts did not smell like anything other than themselves. After receiving compensation (course credit or $20 CAD), scent donors completed a compliance check. Shirts were only retained for men who completed protocols correctly or who reported only innocuous infractions to these stringent rules (e.g. consuming soup that contained small pieces of cooked onion).

2.3.1.2 Shirt Preparation.

Scent donors returned their worn shirts to the lab within five hours of removal. All shirts (including unworn) were turned inside out, folded, and placed in a sealed plastic freezer bag with the underarm section facing the opening. An identifying number was written on the freezer bag after participants left, ensuring that participants were not aware of the number associated with their shirt. They were stored in a -30°C freezer, in line with standard scent preservation methods (Lenochova, Roberts & Havlicek, 2009). Couples were assigned to a condition when they signed up for the study; when women booked their final lab session, they were assigned a shirt number. Women in the partner condition were assigned their partner's worn shirt, women in the unworn condition were assigned an unworn shirt, and women in the stranger condition were assigned a shirt worn by the male partner of a women in one of the other two conditions. In order to control for the amount of time that shirts were in the freezer, stranger shirts were selected by identifying the total freezer time of the most recent partner shirt, and choosing the available shirt that had been in the freezer for the most similar amount of time. All shirts were removed from the freezer one to two hours prior to use in order to ensure they were at room temperature when smelled. Each shirt (including unworn) was smelled by only one woman.

2.3.1.3 Smellers.

To control for differences in cortisol production across phases of the menstrual cycle, female participants, or "smellers," completed the stress test during the luteal phase of their cycle, the phase when women have the most pronounced cortisol stress response (Kirschbaum et al., 1999). Smellers monitored their menstrual cycle using commercially available ovulation strips, which use urine to measure luteinizing hormone; positive results indicate impending ovulation (Guida et al., 1999). When women received a positive result, they were booked for a second lab visit (during their luteal phase, four to eleven days post-positive result). Eighteen women failed to obtain a clear indication of their ovulation status and were not able to complete the study.

2.3.2 Trier Social Stress Test

Smellers participated in the Trier Social Stress Test (TSST, Kirschbaum et al., 1993), a standardized laboratory-based psychosocial stressor involving a mock job interview and an unanticipated mental arithmetic task, which reliably induces physiological and psychological stress (Dickerson & Kemeny, 2004). They arrived to the lab between 3:30 to 6:00 PM for a two-hour session (the restricted time window controlled for diurnal variation in cortisol; Kirschbaum et al., 1999). Using a double-blind procedure, smellers were randomly assigned to smell one of three objects: their partner’s shirt, a stranger’s shirt, or an unworn shirt. Smellers were given no information about the identity of the shirt they were smelling and were merely told they were smelling a shirt “which may be either worn or unworn, according to the condition you were randomly assigned to … there is a low probability that the shirt you smell has been worn by someone you know”. Smellers first provided baseline measures of cortisol and perceived stress; thereafter, women smelled a shirt and completed stress measures throughout the study (Figure 2.1).

Smellers then received information about an upcoming mock job interview and were given five minutes to prepare for the interview. They were then led into another room wherein two trained judges in white lab coats were seated at a table in front of a camera. The ten-minute

TSST stress procedure was conducted according to the original protocol (Kirschbaum et al., 1993). Judges were trained to appear neutral throughout the stress procedure and avoid smiling, nodding, and non-verbal feedback.

At the end of the stress procedure, women were led back to the original testing room, where they completed several questionnaires (e.g. if they believed the scent was that of their partner) and demographic information (e.g., age, relationship length). At the end of the study, the judges joined the experimenter to debrief, thank, and compensate (with $40 CAD or course credit) the participant. Complete protocols, materials and data for all study sessions are available online (https://github.com/MarliseHofer/StressSmell).

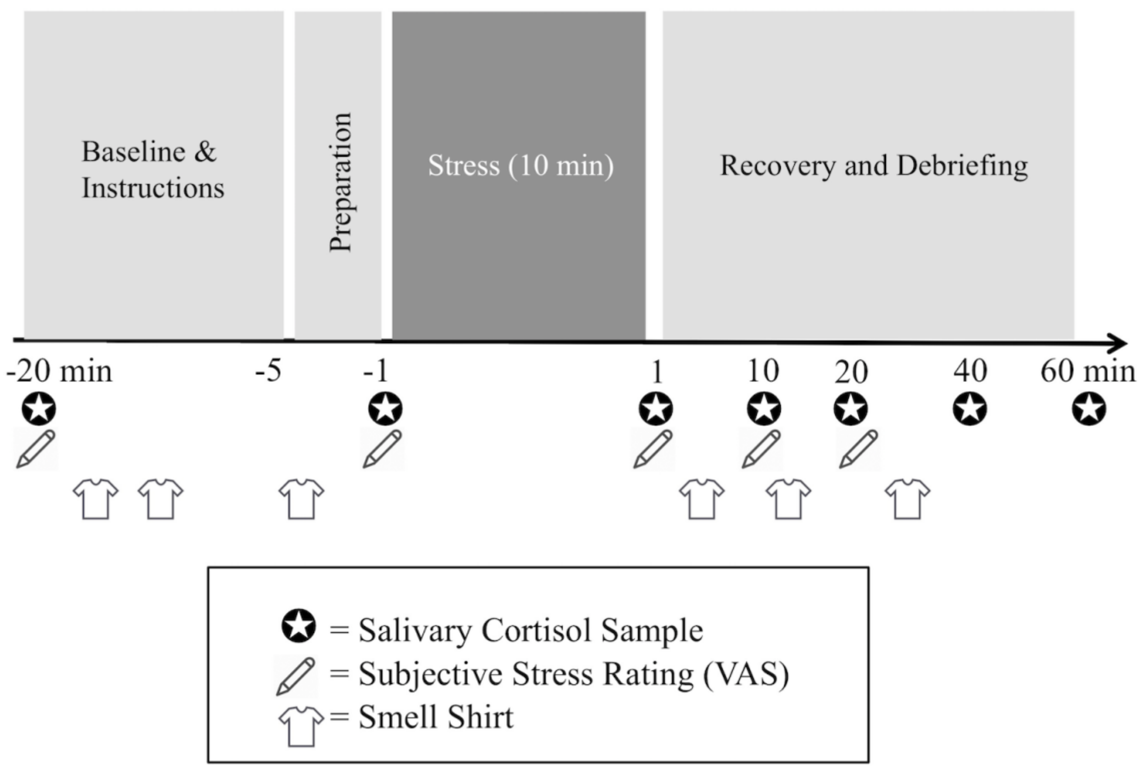

Figure 2.1 Timeline (in minutes) of in-lab component of experiment.

2.3.2.1 Shirt Smell.

Women smelled the same shirt for one minute on six occasions (at -13, -10, -4, +2, +12, and +24 minutes relative to TSST onset). Women were instructed to place their noses a few centimeters from the shirt and inhale deeply (this action was demonstrated by the experimenter prior to the first shirt-smelling occasion).

2.3.2.2 Perceived Stress.

A questionnaire was given five times during the experiment (at -20, -1, +1, +10, and +20 minutes relative to TSST). Women indicated anxiety, physical discomfort, desire to leave the situation, tension, and feelings of control on visual analog scales ranging from 0 (*not at all*) to 100 (*very*) (e.g. Berger, Heinrichs, von Dawans, Way & Chen, 2016; Chen et al., 2011). Perceived stress was computed as the mean of the five items at each time point (feelings of control reverse-scored; Cronbach's alphas for the scale at the individual time points ranged from .70 to .86).

2.3.2.3 Cortisol.

Saliva samples were collected seven times during the experiment (at −20, -1, +1, +10, +20, +40, and +60 minutes relative to TSST) using a standard sampling device (Salivette; Sarstedt). Women were instructed not to smoke (for ten days) or eat or drink beverages containing caffeine or alcohol (for two hours) prior to the lab session. Samples were stored in a freezer at -30°C after each experiment. For biochemical analyses, the samples were spun at 3000 revolutions for 10 minutes to obtain 0.5–1.0 ml of clear saliva with low viscosity. Salivary cortisol concentrations were determined by a commercially available chemiluminescence immunoassay (CLIA; IBL, Hamburg, Germany). Interassay and intra-assay coefficients of variation were below 8%, which indicates good precision (Schultheiss & Stanton, 2009).

2.4 Results

2.4.1 Data Analyses

Perceived stress and cortisol reactions from the ninety-six female participants were analyzed using two-way ANOVAs with repeated measures [scent exposure (partner, stranger, or unworn) x time (repeated factor: 7 for cortisol, 5 for perceived stress)].

2.4.2 Power Analysis

A power analysis was computed, using G Power, with an alpha level of 0.05 and 80% power. An effect size estimate was drawn from previous literature reporting stress reducing effects of partner physical contact (massage) compared to verbal support and no support conditions, which found an effect size of $\eta_2 = 0.05$ (condition by time interaction; Ditzen et al., 2007). The power analysis indicated that the required sample size to detect a condition by time interaction is 81 for perceived stress and 63 for cortisol. Our sample size of 96 exceeds these thresholds, indicating that the study was well powered to test our main hypotheses. Our planned sample size (N=150) would have allowed us to examine predicted individual differences, however these analyses were not explored due to the reduced power.

2.4.3 Perceived Stress

Perceived stress changed over the course of the experiment as expected (significant main effect of time, $F(2.68, 249.44)$[3]= 123.06, $p < .001$, $\eta^2 = 0.57$), indicating that the stress test influenced participant's stress reactions. There was a non-significant main effect of scent exposure ($F(2, 93) = 1.15$, $p = .32$, $\eta^2 = 0.02$) which—of most relevance for our hypothesis—was qualified by a significant interaction between time and scent exposure, $F(5.36, 249.44) = 2.26$, $p = .04$, $\eta^2 = 0.05$. A visual inspection of the data indicates that, compared to women who smelled a stranger's or an unworn shirt, women who smelled a partner's shirt felt less stressed during both anticipation and recovery from the stress task (Figure 2.2).

[3] Throughout the manuscript, Mauchley's test was used to determine if sphericity was violated, and when necessary the Greenhouse-Geisser correction was used (indicated by degrees of freedom with decimal values).

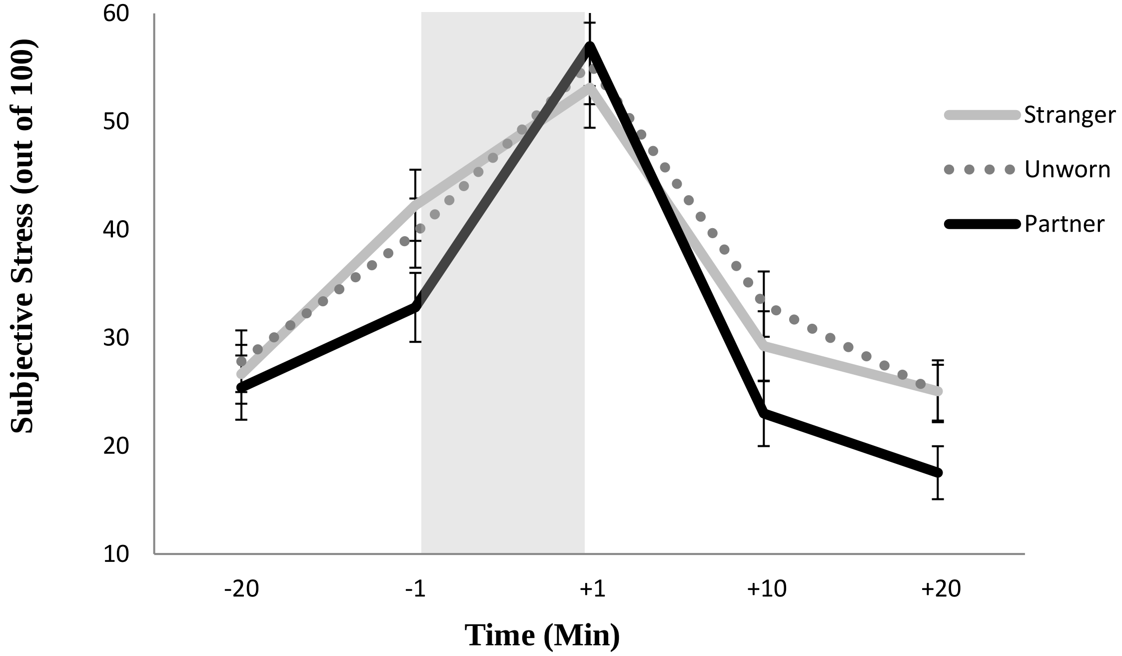

Figure 2.2 Perceived stress by time separated by scent exposure.

Shaded section indicates stress induction (TSST). Error bars represent ±1 SEM.

To follow up on the significant interaction between time and scent exposure, we conducted three regression analyses comparing scent exposure at three phases of stress (anticipatory, peak, and recovery). These phases of stress were tested separately because prior research has shown that social support can be beneficial during both stress reactivity and stress recovery phases (Ditzen et al., 2007; Heinrichs et al., 2003; Meuwly et al., 2012). Two dummy coded variables were created. In the first, partner/unworn were coded as 0, and stranger as 1. In the second, partner/stranger were coded as 0, and unworn as 1. Coding the partner group as 0 for both variables allowed us to directly compare stranger and unworn scents to partner scents (Alkharusi, 2012; Cohen & Cohen, 1983). These two condition variables, along with baseline perceived stress, were used in a linear regression to predict three phases of stress [anticipatory (1 minute pre-stress induction), peak (1 minute post-stress induction) and recovery (mean of 10 & 20 minutes post-stress induction)].

Results revealed that during the anticipatory stress phase, women exposed to their partner's scent reported significantly less perceived stress than those exposed to a stranger's scent (M = 32.81, SD = 18.07 versus M = 42.25, SD = 18.63; perceived stress ratings range from 0 [low] to 100 [high]; p = .017, Table 2.1). During peak stress, scent condition did not predict perceived stress (p's > .39, Table 2.1). During stress recovery, women exposed to their partner's scent reported significantly lower perceived stress than both those exposed to a stranger's or an unworn scent (M = 20.25, SD = 14.96 versus M = 27.14, SD = 16.67 & M = 29.01, SD = 14.19; p = .038 & .015, respectively, Table 2.1). Taken together, these results suggest that women experience a psychological stress-buffering response from exposure to the scent of their partner during both anticipatory stress and stress recovery.

Table 2.1 Perceived stress predicted from scent exposure

	B	***β***	***t***	***p***
Anticipatory				
Partner versus Stranger	8.57	.22	2.43	**.017**
Partner versus Unworn	5.14	.13	1.46	.149
Peak				
Partner versus Stranger	-4.36	-.10	-.059	.607
Partner versus Unworn	-2.62	-.06	-.098	.392
Recovery				
Partner versus Stranger	6.13	.19	2.10	**.038**
Partner versus Unworn	7.25	.22	2.48	**.015**

***Note.* Anticipatory = -1, Peak = +1, Recovery = mean of +10 and +20. Scent exposure dummy coded (partner = 0; other scent exposures = 1). Degrees of freedom = 92. Bold items indicate p < .05.**

2.4.4 Cortisol

Cortisol levels changed over the course of the experiment as expected (significant main effect of time, $F(1.42, 131.76) = 36.32$, $p < .001$, $\eta^2 = 0.28$), indicating that the stress test influenced participant's cortisol responses. There was a non-significant main effect of scent exposure ($F(2, 93) = 0.83$, $p = .44$, $\eta^2 = 0.02$), which—of most relevance for our hypotheses—was qualified by a significant interaction between time and scent exposure, $F(2.83, 131.76) = 3.05$, $p = .03$, $\eta_2 = 0.06$. A visual inspection of the data indicates that cortisol levels after the stress test were elevated for women who smelled a stranger's shirt (Figure 2.3).

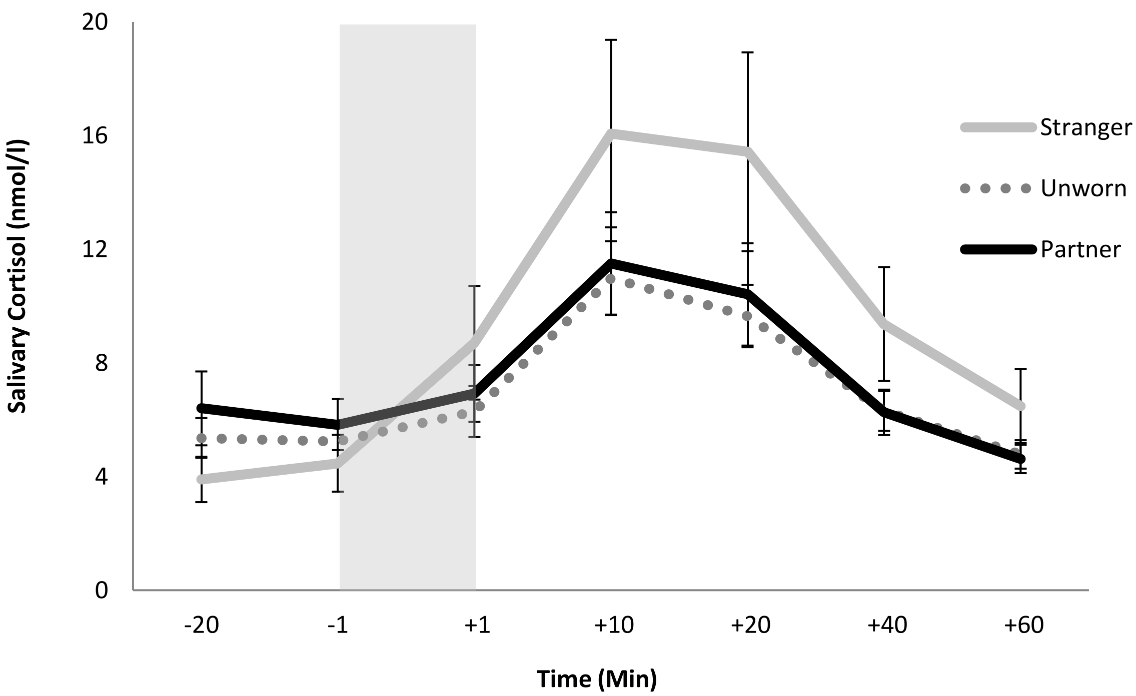

Figure 2.3 Cortisol separated by scent exposure.

Shaded section indicates stress induction (TSST). Error bars represent ±1 SEM.

To explore the interaction between time and scent exposure, a series of linear regression models were used. As in the perceived stress analysis, two dummy coded variables were created. In the first, partner/unworn were coded as 0, and stranger as 1. In the second, partner/stranger were coded as 0, and unworn as 1. The two scent exposure variables and baseline cortisol were used in a linear regression to predict cortisol during three phases [anticipatory stress (1 minute pre-stress induction), peak stress (mean of 10 and 20 minutes after the end of the stressor) and stress recovery (mean of 40 and 60 minutes after the end of the stressor)]. The mean of 10 and 20 minutes after the end of the stressor was used to represent peak stress because salivary cortisol levels are time-lagged relative to the occurrence of an acute stressor by approximately 15 to 30 minutes (de Kloet, Joels & Holsboer, 2005).

Results revealed that cortisol levels were significantly higher in women exposed to a stranger's scent at each stress phase (anticipatory, peak, and recovery, p's < .025, Table 2.2). Cortisol levels did not differ between women exposed to their partner's scent and an unworn scent at any stress phase (p's > .66, Table 2.2). Thus, exposure to the scent of a stranger's shirt led to higher cortisol levels in anticipation of, during, and after a stressful event.

Table 2.2 Cortisol predicted from scent exposure

	B	***β***	***t***	***p***
Anticipatory				
Partner versus Stranger	4.10	.25	2.68	**.009**
Partner versus Unworn	0.32	.02	0.21	.832
Peak				
Partner versus Stranger	7.05	.25	2.28	**.025**
Partner versus Unworn	0.30	.01	0.01	.923
Recovery				
Partner versus Stranger	3.71	.28	2.59	**.011**
Partner versus Unworn	0.61	.05	0.43	.668

***Note.* Anticipatory = -1, Peak = mean of +10 and +20, Recovery = mean of +40 and +60. Scent exposure dummy coded (partner = 0; other scent exposures = 1). Degrees of freedom = 92. Bold items indicate p < .05.**

2.5 Discussion

This study provides evidence that the mere scent of another person can impact psychological and physiological reactions to stress. Women exposed to a stranger's scent displayed elevated cortisol levels throughout a stressful experience, and women exposed to their partner's scent reported less perceived stress both before and after a stressful experience.

With respect to cortisol, a "stranger danger" effect was observed. From infancy onwards, humans are inclined to fear strangers—particularly strange males—a tendency that is theorized to have motivated adaptive responses to the widespread stranger violence in our ancestral past (Hahn-Holbrook, Holbrook, Bering, 2010; Hrdy, 1999; Feinman, 1980). Indeed, when adults view faces of outgroup males, fear responses endure longer (Navarrete et al., 2009; Olsson, Ebert, Banaji & Phelps, 2005). Interestingly, the “stranger danger” effect that we observed was limited to cortisol; we found no evidence that strangers’ scents increased perceived stress. This suggests that cortisol reactions may represent energy mobilization within the metabolic system in preparation for a potential threat (the “fight or flight” response), and that this cortisol reaction may not be accessible to the subjective experience of stress.

With respect to perceived stress, a “partner comfort” effect was observed. Dissociations between cortisol reactions and perceived stress are often noted in the literature (Campbell & Ehlert, 2011; Kirschbaum et al.,1995; Ditzen et al., 2007; Frisch, Häusser, vanDick & Mojzisch, 2014). However, exploratory analyses (available in Appendix A) indicate that, when comparing the partner and stranger conditions, perceived stress levels during the anticipatory stress phase mediate the relationship between condition and cortisol production. Thus, while main effects of perceived stress and cortisol reactions were dissociated, some relationship may exist between the two outcomes.

Why was cortisol not buffered by partner scents (compared to neutral scents)? It is possible that the result reported in Figure 2.3 underestimates the stress-buffering effect of partner’s scent because some women misidentified their partner’s scent as that of a stranger, or vice versa. Indeed, only 63% of women exposed to their partner’s scent believed they were smelling their partner’s scent. Outside the context of a lab experiment, participants are likely to have knowledge about the origin of the scents they encounter (e.g., stranger scents are generally encountered in new social settings; partner scents are encountered when wearing a partner's clothing). Thus, examining only those women who correctly identified the scent to which they were exposed arguably provides additional external validity. Initial evidence indicates that, in the subset of women for whom actual scent exposure and belief about scent exposure match, those exposed to their partner's scent did produce less cortisol. The reduced cortisol in the partner condition (Figure 2.4) was not statistically different from unworn when analyzed using ANOVA, but the difference was significant in an HLM analysis (see Appendix A). Belief about scent exposure may play a crucial role in cortisol reactions to stress, and the physiological stress-buffering effects of a partner's scent may be most apparent when the origin of the scent is known.

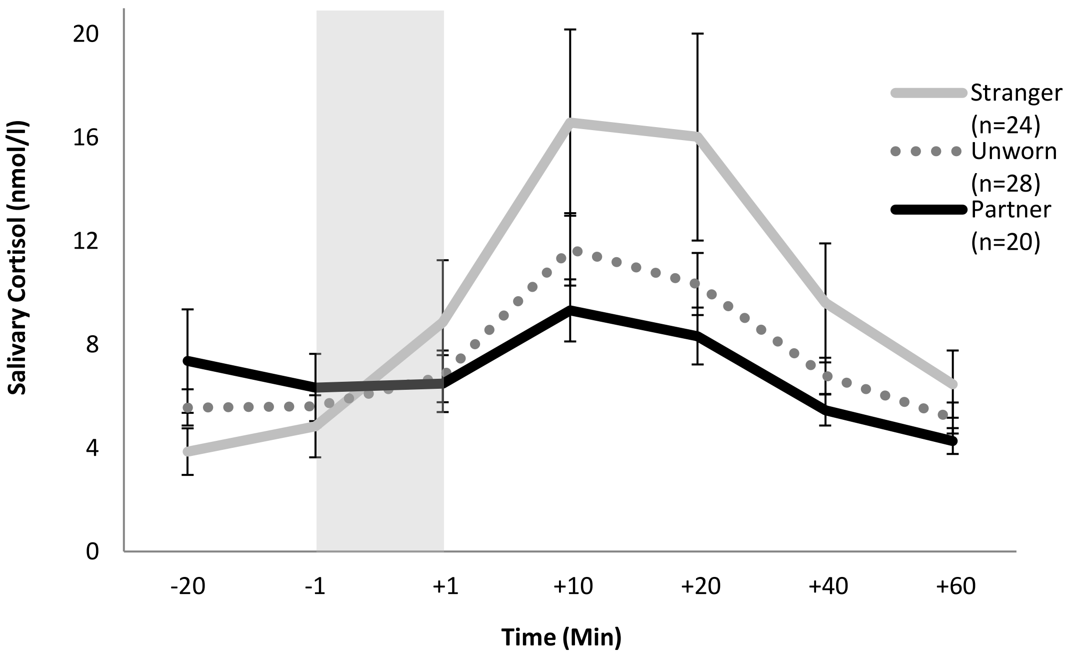

Figure 2.4 Cortisol separated by scent exposure in the subset of participants who correctly guessed whether or not they had been exposed to their partner's scent (*n*=72).

Shaded section indicates stress induction (TSST). Error bars represent ±1 SEM.

Given that belief appears to impact cortisol reactions, we also explored the unique effects of scent exposure and belief about scent exposure on stress reduction. Initial evidence indicates that exposure to a partner's scent alone (in the absence of belief) leads to reduced perceived stress, and believing that one has smelled a partner's shirt leads to reduced cortisol levels (analyses available in Appendix A). Future research on a larger sample or involving systematic manipulation of belief will be necessary to fully disentangle the respective roles of scent exposure and belief about scent exposure.

Based on our power analysis, the current study was well powered to examine main effects of scent exposure on all participants; however, strong conclusions should not be drawn from the results of this one study in isolation. This evidence should be viewed within the growing literature on partner odor. At the moment, two additional related studies exist. The first one, mentioned previously, is a dissertation published in 2009 by Streeter who found that exposure to a partner's scent led to increased comfort, decreased anxiety, and decreased negative affect compared to no scent. In addition, shortly after the publication of Hofer, Collins, Whillans & Chen, 2018 (the paper that this chapter is based on), a study by Granqvist and colleagues (2019) was published that conceptually replicated these findings. Using a very clean within-subjects design, Granqvist and colleagues (2019) subjected participants to mild electric shocks while they smelled several odors. Results indicated that people exposed to their partner's scent experienced less subjective discomfort (compared to when they were exposed to their own body odor). As far as I am aware, these are the only three studies that have tested the effects of partner odor on stress. The direction of the key effect is consistent in all three studies: psychological reactions to stress are attenuated by exposure to a partner's scent. Despite the limitations of each of these individual studies (e.g., small sample sizes), taken together they start to build a case for the possibility that exposure to a partner's scent leads to improvements in the psychological experience of stress.

As this was an early test of social support effects using olfactory cues, strict rules were set (e.g. inclusion criteria, menstrual cycle stage, scent collection procedures) with the goal of reducing measurement error and further enhancing power. These detailed procedures and criteria meant that smellers were all women in the luteal phase of their cycle and in committed heterosexual romantic relationships. The decision to use women as smellers was not based on predicted sex differences, but rather on logistical considerations (e.g. prior research showing that women have a more sensitive sense of smell; Brand & Millot, 2001). Thus, future research will be necessary to determine whether these effects generalize to women in different menstrual phases, to men, and to different social relationships (e.g. homosexual, polygamous, platonic, parental).

Scent collection procedures in this study (and the majority of existing scent research studies) strictly regulate foods and activities of scent donors with the goal of ensuring that natural body odor is not overpowered by external smells. However, consistent scent alterations (e.g., cologne; scented body lotion) may contribute to how a person is generally perceived. Indeed, recent research has demonstrated that perceptions of a person change when smelling a stranger's "altered" body odor versus their "natural" body odor (Gaby & Zayas, 2017). Future research on the benefits of partner odor could profitably compare the stress-buffering effects of natural and altered body odor. This may be especially relevant in cases where a person alters his or her body odor in the same way each day (e.g., daily use of cologne/perfume, shampoos, lotion, deodorant).

This research could be extended to encompass other health-relevant processes. Several positive health behaviors have been linked to social support, such as improved sleep, smoking cessation, and healthy eating (Friedman et al., 2005; May & West, 2000; Nastaskin & Fiocco, 2015; Wing & Jeffery, 1999). The current study indicates that some of the positive effects of social support on stress can be communicated via scent alone. Therefore, future work could examine whether exposure to supportive scents are associated with a broader range of health outcomes.

With globalization, both short-term and long-term separation from social support networks is becoming increasingly common. US residents alone took over two billion trips in 2016 (U.S. Travel Association, 2016), and a 2013 Gallup survey reported that 24% of Americans have moved to a new city in the past five years (with similar numbers reported in other Western cultures; Esipova, Pugliese & Ray, 2013). Individuals separated from loved ones may particularly benefit from a behavioral strategy to reduce stress. From a practical perspective, these findings could be used to develop everyday strategies (which may be as simple as traveling with an article of clothing from a loved one) to promote healthy stress coping during times when people are physically separated from supportive others.

The current work ties together two lines of research, one suggesting that the scent of a close other is pleasant and comforting (Hold & Schleidt, 1977; Shoup, Streeter & McBurney, 2008; McBurney, Shoup & Streeter, 2006), and the second indicating that social support reduces stress reactions (Ditzen et al., 2007; Meuwly et al., 2012; Heinrichs, Baumgartner, Kirschbaum & Ehlert, 2003). The finding that olfactory cues influence psychological and physiological reactions to stress builds upon this existing knowledge and highlights the critical role of olfaction on communication, social support, and health.

Chapter 3: The Scent of a Good Night's Sleep: Olfactory Cues of a Romantic Partner Improve Sleep Efficiency

3.1 Short Summary

Almost nothing is known about whether exposure to the scent of loved ones influences sleep. In the current study, 155 participants spent two nights with their partner's scent and two nights with a control scent (in random order). Sleep was measured in two ways: sleep efficiency (via actigraphy) and perceived sleep quality (via self-report). Sleep efficiency was higher when participants were exposed to their partner's scent. This increase occurred regardless of participants' beliefs about the origin of the scent. Perceived sleep quality was higher when participants believed they were smelling their partner's scent. Exposure to a partner's scent led sleep efficiency to increase by over 2% on average, an improvement similar in magnitude to the effect of melatonin on sleep. The current work speaks to the critical role of olfaction in communication and reveals that social scents can impact sleep.

3.2 Introduction

The scent of another person is emotionally evocative. It can spark sexual attraction, induce fear, and provide psychological comfort (Gildersleeve, Haselton, Larson & Pillsworth, 2012; de Groot, Semin & Smeets, 2017; McBurney, Shoup & Streeter, 2006). Social scents also influence physiological processes such as hormone release, heart rate, and sweat production (Hofer, Collins, Whillans & Chen, 2018; Maner & McNulty, 2013; Granqvist, et al., 2019).

The significance of social scents begins early in life. Newborn babies turn their heads towards their mother's scent and are calmed by this scent (evidenced by decreased movement and cortisol production; Rattaz, Goubet & Bullinger, 2005; Nishitani et al., 2009). Whereas the primary attachment figure for most infants is their mother, the primary attachment figure for most adults is their romantic partner (DeLongis & Holtzman, 2005). Long-term romantic relationships have many positive health implications (see Burman & Margolin, 1992, for a review). Close contact with an attachment figure, such as a romantic partner, provides a sense of emotional security, promotes effective day-to-day functioning (e.g. Brennan & Shaver, 1995), and helps people to regulate (consciously and unconsciously) their physiology and psychology (Bodenmann, Meuwly & Kayser, 2011; Ditzen et al., 2007). For example, research has shown that when couples are together, they report higher quality sleep than when they are physically separated (Diamond, Hicks & Otter-Henderson, 2008).

However, periodic physical separation from romantic partners is inevitable, especially in our highly mobile contemporary society. Fortunately, romantic partners need not be physically present to provide security. Simply viewing a photograph of a romantic partner can be sufficient to buffer reactions to pain (Eisenberger et al., 2011; Younger, Aron, Parke, Chatterjee & Mackey, 2010). Because a romantic partner's scent can also serve as a cue to that person's current or recent presence, we hypothesize that exposure to a romantic partner's scent will help people regulate their psychology and physiology.

3.2.1 The Current Work

Research has demonstrated that exposure to a romantic partner's scent can reduce stress and induce feelings of safety and security (Hofer et al., 2018; Granqvist et al., 2019; McBurney et al., 2006), which may have implications for sleep. Stress and vigilance are antithetical to the state of sleep, while feelings of safety and security are optimal for high quality, consolidated sleep (Troxel, 2010). Thus, in the current work we turn to the question of whether exposure to a romantic partner's scent can improve sleep.

In daily life, people often sleep with a romantic partner's previously-worn clothing while physically separated from their partner (over 70% of women and 25% of men reported this behavior in a sample of US college students; McBurney et al., 2006). However, the effects of this common behavior on people's sleep outcomes have not been systematically studied or quantified. The current work is (to our knowledge) the first attempt to examine whether sleeping with an article of clothing previously worn by a romantic partner improves sleep in adults. In addition, we explore whether conscious awareness of scent identity plays a role in whether sleep is affected by scent.

Participants slept with a shirt worn by their romantic partner (shirts were used as a pillow cover) for two nights and a control shirt for two nights. Sleep quality was assessed via a sleep watch (*sleep efficiency*), as well as via self-report (*perceived sleep quality*). We predicted that, compared to nights spent with a control scent, sleep efficiency and perceived sleep quality would be higher on nights spent with a partner's scent.

These two hypotheses were examined using data from three related samples. Materials, data and R code are available online (https://github.com/MarliseHofer/ScentSleep.git). Data from the three samples are combined in order to increase statistical power. Data collection followed preregistered plans, but the specific data analysis presented here (wherein all samples were combined) was not preregistered. Therefore, the analyses presented in chapter 3 should be considered exploratory rather than confirmatory. Results from preregistered analyses (wherein the three samples are analyzed separately) are available in Appendix B. Preregistrations for each sample can be found at the following links - Sample 1: https://osf.io/3ez5c/; Sample 2: https://osf.io/v2gsv/register/5730e99a9ad5a102c5745a8a; Sample 3: https://osf.io/jsbrn/register/565fb3678c5e4a66b5582f67.

3.3 Methods

3.3.1 Participants

One hundred and fifty five couples, across three samples, completed the study (25% male, 75% female; mean age 20.75 years, *SD* 3.24; relationship mean length 1.9 years, *SD* 2.8). Participants primarily identified as Asian (including South Asian and Indian, 55%), or Caucasian (30%). Participants were eligible to complete the study if they were in heterosexual long-term romantic relationships (> 3 months) and met basic health and screening criteria (e.g., no chronic medical conditions, had the ability to smell, no sleep disorders; see supplemental online materials in Appendix B for full exclusion criteria). Methods were approved by the university's behavioral research ethics board.

3.3.2 Procedures

3.3.2.1 Scent Donors.

Scent donors first washed their bed sheets with unscented detergent and showered using unscented soap. They then wore a white cotton t-shirt under their clothes for 24 hours, refrained from using scented body products, and avoided odor-producing activities (i.e. exercise, sex, smoking, drinking alcohol, eating pungent foods; Maner & McNulty, 2013; Hofer et al., 2018).

Shirts were returned within five hours of wearing, placed into sealed freezer bags, and stored at -20°C (Lenochova, Roberts & Havlicek, 2009).

3.3.2.2 Sleepers.

Sleepers were invited for an initial lab session (taking place on a Monday) during which they received two shirts, identical in appearance: their partner's shirt and a control shirt (either an unworn shirt or a stranger's shirt). For the following four nights, participants slept with one shirt placed over their pillow (Shirt A on Monday and Tuesday, Shirt B on Wednesday and Thursday; shirt order randomized and double blind, Figure 3.1). Participants laundered their bed linens with unscented detergent on Monday and Wednesday (before sleeping with each new shirt), and showered with unscented soap and shampoo before bed (unscented products were provided by us). To reduce sleep disturbances, participants refrained from drinking alcohol or caffeine after 2pm. Participants slept alone throughout the four nights of data collection.

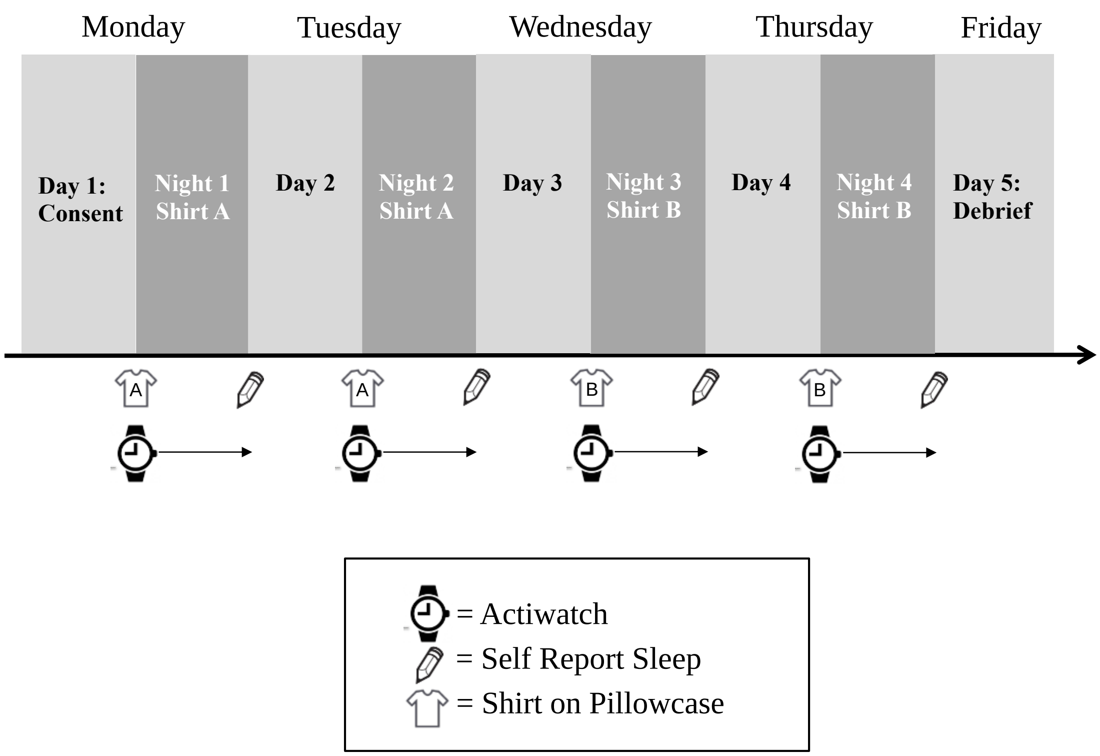

Figure 3.1 Timeline of the sleep procedures.

3.3.3 Variables of Primary Conceptual Interest

3.3.3.1 Sleep Efficiency.

A wrist-worn actigraphy monitor (Philips Respironics Actiwatch 2 watches were used with Phillips Actiware 6 software) recorded participants' sleep/wake intervals each night using epochs 30 seconds in length. Participants were asked to set a marker (by pressing a button on the side of the watch) when they started trying to fall asleep in the evening and when they awoke in the morning. Two participants data did not have markers and three further participants indicated that, in specific instances, the markers they made were inaccurate. In these cases, self-reported sleep/wake times from participant's daily diary reports were used. *Sleep efficiency* was calculated by dividing time asleep over total time in bed attempting to sleep (the period between the evening and morning marker). This measure represents the proportion of time a participant spends asleep out of the total time they spend in bed attempting to sleep. Actigraphy monitors record motor activity and use an algorithm to distinguish sleep from wakefulness. Data from actigraphy monitors are well validated against polysomnography and are used extensively in sleep research (de Souza et al., 2003; Gordon, Mendes & Prather, 2017).

3.3.3.2 Perceived Sleep Quality.

Each morning, participants indicated what time they went to bed and what time they got up. They also answered the following two questions "Last night, how would you rate your sleep quality overall?" and "How well rested do you feel this morning?" (1=Very bad/unrested, 7=Very good/rested; items modified from the Consensus Sleep Diary, Carney et al., 2012). These two items were averaged to form a measure of *perceived sleep quality* (all within-participants correlations were performed as described in Bakdash & Marusich, 2017; r =.53, p<.001, 95% CI [0.46, 0.59]). One participant was given an incorrect version of the questions (referring to the previous month) and was excluded from analyses on perceived sleep quality.

3.3.4 Control Variables

3.3.4.1 Perceived Stress.

Each evening, participants answered the questions "How stressful was your day today?" and "How stressful do you expect your day tomorrow will be?" (1=Very Unstressful, 3=Fairly Unstressful, 5=Fairly Stressful, 7=Very Stressful). These two items were averaged (r =.19, p<.001, 95% CI [0.10, 0.28])) to form a measure of *perceived stress.* Some participants wrote a response (e.g., "not very stressful") rather than using the scale. Out of the total 620 nights (4 nights * 155 participants), this occurred 4% of the time (25 times). On nineteen of these occasions, the first author translated the response provided by the participant into a numeric scale response (e.g. "not very stressful"=2)[4]. The remaining six occasions could not easily be coded (e.g. "good") and were removed from analyses that include perceived stress.

3.3.4.2 Weeknight.

Night of the week was recorded (1=Monday, 2=Tuesday, 3=Wednesday, 4=Thursday). As the week progressed, people reported higher perceived sleep quality (means were 4.5, 4.6, 4.8 and 4.8, respectively on the 7-point scale). Thus, to control for changes in perceived sleep quality over the week, weeknight was used as a linear time variable.

3.3.4.3 Additional Measures.

In the initial lab visit, all participants completed questionnaires assessing relationship quality (Perceived Relationship Quality Components; Fletcher, Simpson & Thomas, 2000), attachment style (Adult Attachment Questionnaire; Simpson, Rholes & Phillips, 1996), as well as questions assessing their sex and relationship length.

3.3.5 Methods for Each Sample.

A two-tailed paired sample t-test with N=40, and a medium effect size (d = 0.5) has a power of 87%. The effect size of d = 0.5 was chosen because a recent meta-analysis on common sleep aids reported effect sizes in the medium to large range (Buscemi et al., 2007). Based on this power analysis, we recruited three samples with 40 couples in each condition. Initially, each sample

4 Excluding all twenty-five nights does not significantly change the results or their inferential implications.

was designed to address multiple research questions (described below): some that were similar across samples, and some that were unique to that specific sample. In retrospect, we believe that the effect size used (based on the effect of pharmaceutical grade sedatives on sleep) was overly optimistic. The magnitude of the effect we actually found was more similar to that of melatonin on sleep efficiency (2.2%; Brzezinski et al., 2005). Due to concerns about analyses on individual samples being underpowered, we decided to combine data and focus on the overarching research questions that were similar across samples (demographics reported above are combined across samples and do not significantly differ between samples). Using a power of 80% and a two-tailed test, the combined sample (N=155) allows for detection of even a small effect (d = 0.23).

The first sample examined whether female participants' sleep improves with exposure to the scent of their partner, compared to no scent. Forty couples were recruited; females served as sleepers and males as scent donors. Females spent two nights with their partner's shirt as a pillow cover and another two nights with a control (unworn) shirt as a pillow cover. The second sample examined the same effect in a different group of females and additionally examined whether the effect extended to males. Forty couples were again recruited; however, in this sample both members of the couple (females and males) served as scent donors and sleepers. The third sample compared exposure to the scent of a partner to a different control scent: namely, the scent of a stranger. Forty couples were recruited; as in sample 1, females served as sleepers and males as scent donors. In this sample, male scent donors provided two shirts (they wore the shirts consecutively using the scent protocols outlined above). One shirt served as their female partner's "partner" scent, and one shirt served as another couple's "stranger" scent. Each female participant in sample 3 spent two nights sleeping with her partner's shirt and two nights with a stranger's shirt.

During data collection for sample 1, one relationship ended, and two couples failed to adhere to instructions not to sleep in the same bed. These unforeseen circumstances caused our final sample 1 size to be 37 (fewer than the planned 40). To avoid this issue in samples 2 and 3, participants were recruited until the sample of 40 analyzable females was reached (analyzable defined as having at least one night of sleep efficiency data for the partner condition and the control condition). This resulted in a total sample of 40 females and 38 males in sample 2 and forty females in sample 3.

A total of 25 participants were excluded from samples 2 and 3: four for sleeping in the same bed as their partner, three for being unsure which order they slept with shirts, two for switching experimental shirts with their partner (sleeping with their own scent instead of their partner's scent), two for not adhering to preregistered cigarette and marijuana restrictions during scent collection, five for not fitting preregistered eligibility requirements regarding smoking and drug usage, one for being given incorrect materials by the experimenter, and eight for malfunctioning sleep watches.

In total, we analyzed data from 155 participants (Sample 1=37 females; Sample 2=40 females and 38 males; Sample 3=40 females). Descriptive and inferential statistics on data broken out by sample are displayed in Figures 3.2 and 3.3.

3.4 Results

3.4.1 Multilevel Models on Combined Data

Data included within-person measures of sleep across four nights. To account for the clustered nature of the data, multilevel modeling (MLM) was used. MLM models were estimated using R and the multilevel modeling package lme4 (R Core Team, 2018; Bates, Mächler, Bolker &

Walker, 2015). Repeated measures of sleep (Level 1) were nested within individuals (Level 2) and a random slope model was used. Because couples were not allowed to share the same sleep environment, they were not expected to influence one another's sleep. Thus, a couple level was not added to the model (ICC's were also rather low: sleep efficiency < 0.001; perceived sleep quality = 0.13). However, results of a three-level model which includes the couple level can been seen in Appendix B and are very similar, with identical inferences, to the results reported here.

3.4.1.1 Initial MLM model.

The initial model measuring the effect of scent type (0=control; 1=partner) on sleep employs the following equations:

Level 1: $\text{Sleep}_{ij} = b_{0j} + b_{1j}(\text{Scent}_{ij}) + e_{ij}$

Level 2: $b_{0j} = \gamma_{00} + u_{0j}$

$b_{1j} = \gamma_{10} + u_{1j}$

3.4.1.2 Sleep Efficiency.

As predicted, mean sleep efficiency was higher on nights spent with a partner's shirt than a control shirt (*M*=88.03%, *SD*=6.50% and *M*=85.35%, *SD*=10.26% respectively, *d*=0.31[5], *95% CI* [0.09; 0.54]). The initial multilevel model (using equations above) indicated that scent type was a significant predictor of sleep efficiency (*b*=2.58, *SE*=0.76, *p*<.001, *95% CI* [1.10; 4.05][6,7]).

[5] Cohen's *d* was calculated by comparing mean sleep on nights spent with the partner scent compared to nights spent with the control scent using the "effsize" package in R for paired samples.
[6] Upon visual inspection, it is apparent that two values for sleep efficiency are extreme outliers (10% and 20% – the next lowest value was 42%). Removal of these two nights does not change the direction or inferential implications of the results (*b* = 2.02, *SE* = 0.67, *p* = .003, *95% CI* [0.58; 3.31]).
[7] Throughout the paper, bootstrapped confidence intervals are presented using 1000 simulations.

To control for other pertinent variables, an additional multilevel model was computed simultaneously including several control variables as predictors[8]. Covariates were preregistered for samples 2 and 3 (aside from control scent, which varied between samples), and were chosen either due to their predicted relationship to sleep or to control for any experimental or order effects. All validated scales measured in the study are included as covariates. Predictors added at Level 1 include: Daily Perceived Stress & Weeknight. Weeknight (scored as 1-4 representing Monday through Thursday) was centered by subtracting by the mean (2.5). Perceived Stress was cluster centered within person. Predictors added at Level 2 include: Control Scent, Avoidant & Ambivalent Attachment, Participant Sex, Relationship Length, Relationship Quality, and Order. All continuous control variables measured at the person level (level 2) were centered around their grand mean (these include: Relationship Quality, Relationship Length, Avoidant Attachment style, and Ambivalent Attachment style). The dummy coded variable *control scent* indicates which control scent a participant slept with (unworn shirt=0; stranger's shirt=1). The mean perceived stress level for each person across all four days was included as a measure of *average perceived stress* (Level 2) and grand mean centered. Unlike analyses in chapter 2, menstrual cycle stage was not included as a covariate we did not have reason to believe this variable would impact sleep (but we did believe it may impact cortisol reactivity in chapter 2).

Next, non-significant predictors (using a relaxed threshold of p<.10) were removed to create a more parsimonious model (Results including all predictors simultaneously can be seen in Appendix B: in these analyses the relationship between scent and sleep efficiency is very

[8] Results from models examining moderation (including interactions between control variables and scent) are explored in Appendix B

similar, with identical inferences, to the relationship reported here). The final model (equation below) has two predictors: Scent and Sex[9] .

Level 1: $Sleep_{ij} = b_{0j} + b_{1j}(Scent_{ij}) + e_{ij}$

Level 2: $b_{0j} = \gamma_{00} + \gamma_{01}(Sex_j) + u_{0j}$

$b_{1j} = \gamma_{10} + u_{1j}$

Table 3.1 HLM predicting sleep efficiency from scent and participant sex.

Fixed effects:	Unstandardized ***b (SE)***	***p***	***95% CI***
Scent	2.59 *(0.76)*	<.001	1.09, 3.99
Participant Sex	-2.71 *(1.11)*	.016	-0.49, -5.03

***Note.* Scent coded as 0=control, 1=partner; Participant Sex coded as 0=female, 1=male; Participants *N*=155; Nights *N*=610; ICC=0.20; Random Effects: Intercept variance=53.25, Slope Variance=23.10; REML Estimation used; Unstandardized regression coefficients presented.**

Results indicate a relationship between participant sex and sleep, indicating that on average females have higher sleep efficiency than males. In addition, even controlling for a number of potentially-related variables, scent type positively predicts sleep efficiency, indicating that sleeping with a partner's scent leads to increased sleep efficiency.

[9] See Appendix B for analyses predicting other sleep outcomes (onset latency and wake after sleep onset). Similar to sleep efficiency, these sleep outcomes are also reduced by exposure to a partner's scent.

3.4.1.3 Perceived Sleep Quality.

Although perceived sleep quality was descriptively higher on nights spent with a partner's shirt than a control shirt (*M*=4.74, *SD*=0.85 and *M*=4.60, *SD*=0.87 respectively, *d*=0.16, *95% CI* [-0.06; 0.38]), the initial MLM indicated that this difference was not statistically significant (*b*=0.15, *SE*=0.08, *p*=.074, *95% CI* [-0.01; 0.31]). Equations used for the initial MLM were identical to those used for sleep efficiency.

To control for other variables and detect potential moderators, an MLM was performed predicting perceived sleep quality from a larger set of variables (identical to those described for sleep efficiency). The final parsimonious model (shown in Table 3.2) includes three significant predictors (scent type, weeknight, and perceived stress) and employed the following equations:

Level 1: $\text{Sleep}_{ij} = b_{0j} + b_{1j}(\text{Scent}_{ij}) + b_{2j}(\text{Perceived Stress}_{ij}) + b_{3j}(\text{Weeknight}_{ij}) + e_{ij}$

Level 2: $b_{0j} = \gamma_{00} + u_{0j}$

$b_{1j} = \gamma_{10} + u_{1j}$

$b_{2j} = \gamma_{20}$

$b_{3j} = \gamma_{30}$

Table 3.2 Hierarchical linear models predicting perceived sleep quality from scent type, perceived stress, and night

Fixed effects:	Unstandardized ***b (SE)***	***p***	***95% CI***
Scent	0.18 *(0.08)*	.030	0.02, 0.33
Weeknight	0.06 *(0.04)*	.078	-0.01, 0.14
Perceived Stress	-0.19 *(0.05)*	< .001	-0.27, -0.10

***Note.* Scent coded as 0=unworn, 1=partner; Weeknight coded 1=Monday, 2=Tuesday, 3=Wednesday, 4=Thursday; Perceived stress measured on a 7-point Likert scale; Participants *N*=154; Nights *N*=605; ICC=0.19; Random Effects: Intercept Variance=0.31, Slope Variance=0.14; REML Estimation used. Unstandardized regression coefficients presented.**

Results indicate that on days when perceived stress was higher, perceived sleep quality was lower. In addition, when daily stress and weeknight are included in the model, exposure to a partner's scent did significantly increase perceived sleep quality.

We also tested whether a relationship existed between sleep efficiency and perceived sleep quality. These measures of sleep were weakly correlated (r =.11, p=.017, *95% CI* [.02 .20]).

3.4.1.4 Discussion

Exposure to the scent of a partner increased sleep efficiency, and this relationship remained significant even when controlling for attachment style, relationship length and quality, stress level, day of the week, order of scent exposure, and type of control scent.

Exposure to the scent of a partner did not significantly increase perceived sleep quality. However, when adding perceived stress and weeknight to the model, exposure to the scent of a partner did significantly increase perceived sleep quality.

3.4.2 Internal Meta-Analysis

The preceding analysis combined data collected across three samples. To ensure that this combination does not obscure differences across samples, we performed a second analysis on the same data, resulting in similar conclusions. A forest plot with results by sample appears in Figures 3.2 and 3.3. A fixed effects internal meta-analysis (with mean effect sizes weighted by the inverse of their variance) confirmed that sleeping with a partner's scent resulted in improved sleep efficiency, mean difference=2.14, Z=2.74, p=.006, 95% CI [0.61, 3.68])[10,11]. A second fixed effects internal meta-analysis confirmed that the difference in perceived sleep quality was non-significant, mean difference=0.14, Z=1.76, p=.078, 95% CI [-0.02, 0.30]). These internal meta-analyses did not include covariates, and results are therefore comparable to the initial models described above.

The merits of internal meta-analysis are currently heavily debated, with highly respected scientists arguing both against (Vosgerau, Simonsohn, Simmons & Nelson, 2018) and in favor of internal meta-analysis (Cumming, 2018). The concerns raised by the former group are based on the fact that the validity of a meta-analysis (internal or otherwise) rests on two assumptions that often cannot be established. First, that the studies included in the meta-analysis are free of *p*-hacking, and second, that all of the valid studies that were conducted are included. In this case, we pre-registered our studies, substantially lowering the risk that they could have been contaminated by even unintentional *p*-hacking (although we do note that only two of our three preregistrations included an analysis plan). Furthermore, we have full knowledge that the three studies included are the only ones that have been run by our lab on this topic. After careful consideration, I believe that an internal meta-analysis is the best way to take advantage of the

[10] The metafor package in R (Viechtbauer, 2010) was used to produce the graph and analysis

[11] Results from a random effects test (using maximum likelihood estimation) yielded comparable results: mean difference=2.57, Z=2.13, p=.033, 95% CI [0.21,4.93]).

additional power offered by combining our three samples, while also making the differences across the three samples transparent for readers.

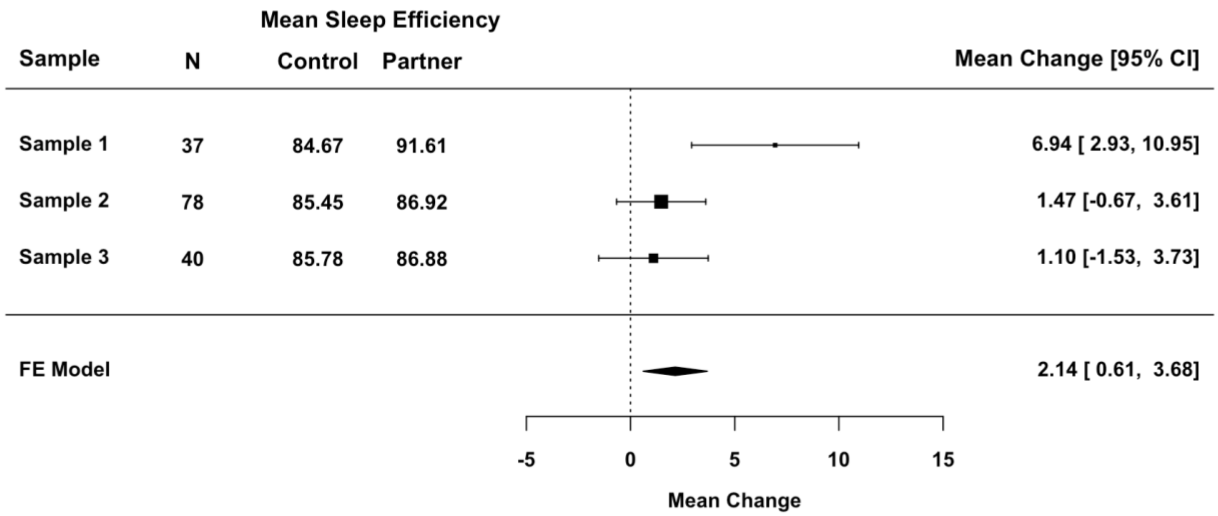

Figure 3.2 Forest plot of sleep efficiency.

Mean sleep efficiency in each of the control and partner conditions of Samples 1 through 3, along with a forest plot showing the mean change between the conditions in each sample. The size of each square in the forest plot is proportional to the weight of that sample. The estimate for the fixed-effects model is also given. CI = confidence interval.

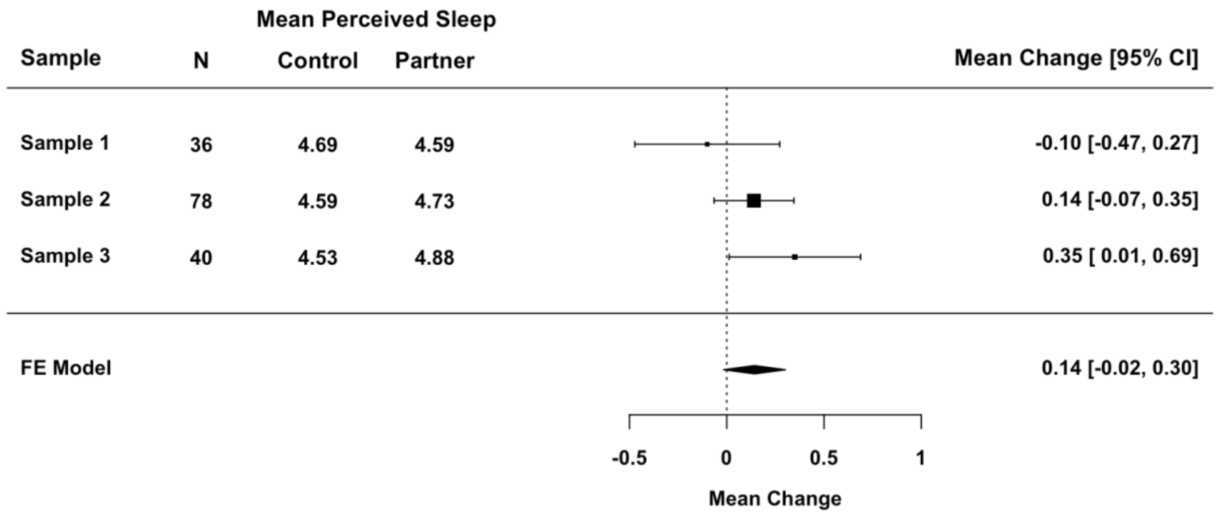

Figure 3.3 Forest plot of perceived sleep quality data.

Mean perceived sleep quality in each of the control and partner conditions of Samples 1 through 3, along with a forest plot showing the mean change between the conditions in each sample. Mean perceived sleep quality was rated on a scale from 1 to 7, with 7 indicating highest sleep quality. The size of each square in the forest plot is proportional to the weight of that sample. The estimate for the fixed-effects model is also given. CI = confidence interval.

3.4.3 Belief Versus Actual Scent Exposure

Were participants able to identify the scents to which they were exposed, and how did their beliefs interact with the effect of scent on sleep? To explore these questions, a variable "belief" was created. Each night, participants were coded as believing the scent was their partner's (1) or not believing the scent was their partner's (0). Participants were able to identity their partner's scent at levels above chance (70% accuracy; Table 3.3).

Table 3.3 Number of nights during which participants believed they were exposed or not exposed to their partners' scent

	Believed Exposure		
Actual Exposure	Partner Scent	Not Partner	Total (n)
Partner Scent	204	105	309
Control Scent	78	232	310
Total (n)	282	337	619

3.4.3.1 Sleep Efficiency.

In order to determine if participants' sleep efficiency was impacted by exposure to their partner's scent, their belief about the scent to which they were exposed, or some interaction of these variables, an MLM model was computed predicting sleep efficiency from scent type, belief, and the interaction of the two, employing the following equations:

$$\text{Level 1: } Sleep_{ij} = b_{0j} + b_{1j}(Scent_{ij}) + b_{2j}(Belief_{ij}) + b_{3j}(Scent_{ij})*(Belief_{ij}) + e_{ij}$$

$$\text{Level 2: } b_{0j} = \gamma_{00} + u_{0j}$$

$$b_{1j} = \gamma_{10} + u_{1j}$$

$$b_{2j} = \gamma_{20} + u_{2j}$$

$$b_{3j} = \gamma_{30}$$

Results indicated that the interaction between scent and belief was not significant (p=.73). When the interaction term was removed, scent (b=2.42, SE=0.79, p = .002, *95% CI* [0.89; 3.92]) but not belief (b=0.45, SE=0.79 p = .57, *95% CI* [-1.04; 1.99]) significantly predicted sleep efficiency. Therefore, results suggest that people who are actually exposed to their partner's scent (regardless of whether they believed they were smelling their partner's scent) experienced improved sleep efficiency.

3.4.3.2 Perceived Sleep Quality.

A second analysis was computed predicting perceived sleep quality using the same model described above. Results indicated that the interaction between scent and belief was not significant (p=.74). When the interaction term was removed, belief (b=0.26, SE=0.10, p=.008, *95% CI* [0.07; 0.45]), but not scent type (b=0.04, SE=0.09 p=.67, *95% CI* [-0.14; 0.22]) significantly predicted perceived sleep quality[12]. In other words, on nights where they believed they were sleeping with their partner's shirt they also reported having slept better. Therefore, our results are in line with the idea that people who believed they were smelling their partner's scent (regardless of whether they were actually exposed to their partner's scent) experienced improved perceived sleep quality. However, it is also possible that these results are due to demand characteristics: when participants believed they were sleeping with their partner's scent, they reported better sleep because they correctly guessed that this was our hypothesis.

3.4.3.3 Discussion

Participants' beliefs about the scent to which they were exposed did not influence their sleep efficiency (measured using actigraphy). However, participants' beliefs about the scent to which

[12] Adding covariates from Table 3.3 (weekday and stress) does not significantly change our results or their inferential implications.

they were exposed did predict their perceived sleep quality. Specifically, participants who thought they were sleeping with a partner's scent experienced improved perceived sleep quality independent of the (nonsignificant) effect of actual scent exposure. These results are in line with previous research which indicates that people believe that their partner's scent is calming (McBurney et al., 2006), as well as our own prior work suggesting that beliefs play a role in the effects of a partner's scent on stress (Hofer et al, 2018).

3.5 General Discussion

The present study examined whether mere exposure to the scent of a romantic partner can improve sleep. We found that exposure to the scent of a romantic partner overnight leads to improved sleep efficiency. Participants in our study experienced an average of over nine additional minutes of sleep per night when exposed to the scent of their partner, equating to more than an hour of additional sleep per week. This increase was achieved without participants spending any more time in bed. As shown in Figure 3.2, sleep efficiency increased by an average of 2.1%, an effect similar in magnitude to the effect of melatonin on sleep (2.2%; Brzezinski et al., 2005). This increase in sleep efficiency appears to occur outside of conscious awareness: beliefs about the scent's identity do not influence the positive impact of exposure to a partner's scent on sleep efficiency. In other words, people sleep better when exposed to their partner's scent regardless of whether or not they thought they were exposed to their partner's scent.

Perceptions of sleep quality also improved with exposure to the scent of a romantic partner, but only when controlling for other factors (e.g. daily levels of stress). When pitting scent type against beliefs about scent identity, belief about scent identity emerged as the only significant predictor of perceived sleep quality. Thus, when people believe that they are smelling their partner's scent, they also report that they are sleeping better.

We found distinct effects of a partner's scent on sleep efficiency (measured via actigraphy) and perceived sleep quality (measured via self-report). Indeed, sleep efficiency and sleep quality were only weakly correlated in our study and were affected differently by our manipulation, a difference that is consistent with prior research (e.g. Lockley, Skene, Arendt, 1999; Russell et al., 2016). Perceived sleep quality in our study was influenced by several psychological factors including daily stress and belief about scent identity, whereas sleep efficiency was influenced by objective differences such as the sex of the sleeper. Perceived sleep quality and sleep efficiency have both been associated with long-term term health outcomes (Thurston et al., 2017; Aziz, 2017), yet they seem to overlap only weakly when measured in parallel. Thus, our recommendation is that future research continue to assess both measures of sleep.

Strangers' scents may provide an interesting avenue for further research. When a stranger's scent was used as the control odor (Sample 3), the contrasting effect of a partner's scent on sleep efficiency was less pronounced, than when a clean scent was used as the control odor (Samples 1 and 2). This suggests that, overall, the smell of a stranger may have a mildly positive effect on sleep relative to no scent. However, initial evidence (available in Appendix B) also suggests that people's responses to the stranger's scent varied considerably. Interestingly, higher ratings of the pleasantness of the stranger's scent were positively associated with reduced sleep efficiency. We hesitate to overinterpret this unexpected finding, but note more generally that researchers should keep in mind that a stranger's scent likely creates its own, potentially complex, manipulation. The design of the current study does not allow us to examine in a nuanced way how strangers' scents may influence sleep quality, but this could be a fruitful direction for future research.

Individual differences (such as participants' sex and relationship characteristics) are likely to moderate the way in which scent affects sleep. The current study was not designed to examine these possibilities; however, on an exploratory basis, the moderating effects of our control variables were examined (these results—available in Appendix B—suggest that female sleepers may benefit more from exposure to their male partners' scent, than vice versa).

In today's highly mobile society, separation from loved ones is quite common. During these separations, individuals are particularly vulnerable to sleep disturbances and a behavioral intervention to improve sleep may be especially valuable. The negative effects from sub-optimal sleep on health and well-being are substantial (Heslop, Smith, Metcalfe, Macleod & Hart, 2002) and widespread (one in three people report recurring sleep irregularities; Ohayon, 2002). Learning how naturalistic behaviors—as simple as sleeping with a loved one's worn article of clothing—affect sleep, may help to eventually uncover the makings of a good night's sleep.

Chapter 4: Concluding Discussion

4.1 Summary

The research presented in this dissertation adds to a small prior literature examining the influence of the scent of a loved one. These findings indicate that smell cues may tacitly connote the presence of familiar people, even when those people are physically absent, with potentially important health consequences—such as reduced reactions to stressful events and improved likelihood of getting a good night's sleep.

Table 4.1 Perceived and objective responses to exposure to the scent of a partner and beliefs about that scent.

	Perceived (Stress/Sleep Quality)			Objective (Cortisol/Sleep Efficiency)		
	Main Effect of Scent	Main Effect of Belief	Scent plus Belief	Main Effect of Scent	Main Effect of Belief	Scent plus Belief
Stress	+	*ns*	+	*ns*	*ns*	+
Sleep	*ns*	+	+	+	*ns*	+

***Note*. Main effect of scent refers to the effect of exposure to a partner's scent compared to a control scent in the entire sample (Stress *N*=96 females; Sleep *N*=619 nights). Main effect of belief refers to the effect of someone believing they are smelling their partner's scent compared to a control scent in the entire sample *controlling for actual scent exposure*. Scent plus belief refers to the effect of exposure to a partner's scent in a subset of people/nights in which scent exposure was correctly identified (Stress *n*=72 females; Sleep *n*=436 nights). A "+" indicates a statistically significant change in a positive direction (stress reduction / sleep improvement).**

The influence of a partner's scent on health-relevant outcomes was not always the same across outcomes (see Table 4.1 for an overview of how specific outcomes were affected—or not affected—by a partner's scent). The main goal of this program of research was to determine whether exposure to a partner's scent led to improved health-relevant outcomes (white columns in Table 4.1). Results indicate that there were two main effects of exposure to a partner's scent: 1) reduced perceived stress, and 2) improved objective sleep efficiency. Neither of these effects were influenced by what the participants believed they were smelling. In other words, both participants who were aware they were exposed to their partner's scent, and those who were not aware of this fact, benefited from exposure to their partner's scent. These results indicate that mere exposure to a romantic partner's scent has positive impacts on some health-relevant outcomes.

I also examined the role of beliefs about scent exposure (light grey columns in Table 4.1). This line of inquiry was not part of my dissertation at the outset, but is addressed here in an exploratory fashion due to its interest value. Unlike scent exposure, beliefs about scents were not manipulated (participants were not told what scent they were supposedly smelling). Thus, directional conclusions cannot be drawn from these findings. Results indicate that one main effect was associated with belief about exposure to a partner's scent: improved perceived sleep quality. This finding indicates that, above and beyond actual scent exposure, people who believed they were smelling their partner also reported improved perceived sleep quality.

Finally, I examined whether scent exposure plus belief predicted health-relevant outcomes (specifically, participants who were exposed to the scent of their romantic partner combined with the [correct] belief that they were smelling their partner's scent; the dark grey columns in Table 4.1). To do this, I examined a subset of the data in which participants correctly identified the scent they were exposed to. When people were exposed to their partner's scent *and* they (correctly) believed they were smelling their partner, all outcomes in Table 4.1 were positively affected (perceived stress, perceived sleep quality, cortisol, and sleep efficiency). This is arguably the most ecologically valid group of people because, in real life, people are usually aware when they are exposed to their partner's scent (such as when they choose to wear their partner's used clothing or sleep on their partner's side of the bed). However, it should be noted that people who believe that they are smelling their partner's scent may also be influenced by demand characteristics, especially in the case of self-report measures. In order to fully disentangle when belief, scent exposure, or a combination of the two is necessary for health benefits, future research will need to manipulate beliefs about scent exposure.

These data indicate that exposure to the scent of a romantic partner affects perceived stress and sleep efficiency, both crucial aspects of health that are linked to virtually every other facet of physical and mental health (including cognitive functioning, life satisfaction, disease risk, and mortality). What other health-relevant outcomes might be affected by a loved one's scent? Since almost half of Americans report coping with stress by overeating or eating unhealthy foods (APA, 2007), might smelling a partner's scent improve health behaviors such as deciding to forgo a cookie before a stressful presentation? And after a long-term partner passes away, could smelling their used clothing ease distress? The answers to these questions remain a task for future research.

The data presented in this dissertation indicates that believing you are exposed to your partner's scent is linked to improved perceived sleep quality. This is in accordance with past research indicating that relational reminders of support providers can have health benefits. Visual reminders of a romantic partner can lead to reduced reports of pain (Master et al., 2009), and merely writing about a romantic partner (e.g. answering a writing prompt such as "what do you appreciate about this person") can reduce cardiovascular relativity to a stressor (Smith, Ruiz, & Uchino, 2004). The research reported here adds to this growing body of work demonstrating that symbolic reminders of social connection are linked to health-relevant outcomes.

By combining two divergent methodologies, this dissertation provides evidence about the role of olfactory cues on two distinct health-relevant outcomes (stress and sleep) from both a highly-standardized and controlled laboratory assessment as well as within a more naturalistic context. In addition, this work adds to our understanding of the connection between everyday behaviors and health outcomes. My hope is that this research will eventually form the basis of further investigation on stress-coping and sleep improvement strategies in daily life that can be readily applied across a broad range of situations.

4.2 Limitations

This section provides an overview of some of the limitations of the data collected for my dissertation. I will describe two types of limitations connected to these findings: those relating to accuracy (sample size, preregistrations), and those relating to generalizability (types of romantic relationships examined, the relatively short length of those relationships).

4.2.1 Accuracy

The sample size in Chapter 2 was small. Ninety-six females participated across three conditions, meaning that only 32 females were included in each experimental condition (stranger, partner, and unworn shirt). A power analysis indicated that this resulted in adequate power to detect our hypothesized main effects. However, the limited number of participants means that there are follow-up questions—such as the impact of relationship quality or attachment orientations—that can only be examined within the 32 females exposed to their partner's scent. Unfortunately, any analyses on these females are severely underpowered and results on these data are not able to offer satisfying conclusions.

The data used in Chapter 3 came from a larger sample (*N*=155), and the within-subject design of these studies gave us more power to examine individual differences, although larger sample sizes would still have been ideal (sample sizes of ~250 are generally recommended for correlations; Schönbrodt & Perugini, 2013). On an exploratory basis, some of the individual differences mentioned above were examined in this sample. Very few statistically significant results emerged (results can be seen in Appendix B); however, some interesting trends did emerge (e.g. relationship length positively predicted the effectiveness of scent exposure on sleep improvement); these analyses may aid in hypothesis generation for future work.

Readers should also be aware of the limitations of the preregistrations associated with this work, which—in retrospect—should have been more detailed. In order to constrain researcher degrees of freedom, a high quality preregistration includes information about the hypothesis, design, and analysis planned for each study. Two of my four preregistrations did not include an analysis plan. Even the two studies with analysis plans only presented preregistered analyses in the appendix. The analyses presented in the main text were not preregistered. While the reasons for these deviations can be easily explained (early attempts at preregistration and combining three samples to increase statistical power), this still means that, even though the preregistrations offer some reassurance, all analyses presented in the main text of this dissertation should be considered exploratory (not confirmatory).

I have four pieces of advice to offer others (and my future self) to help avoid the preregistration pitfalls that I encountered. First, preregister not only a final sample size, but also a date at which data collection will end if the preregistered sample size has not been met (you never know what unforeseen obstacles may impede your data collection). Secondly, if possible, gather data from a small pilot sample with which to generate an analysis plan (such as an R code). Many of my mistakes occurred because I had not realized the form my data would take or where missing data was likely to occur. Third, no matter how conscientious you are, deviations from preregistrations may still be necessary. If you clearly indicate when and why you deviate from your preregistration, most people will accept these deviations. Finally, you cannot please everyone. Best standards for preregistration are currently fluid, and no matter what you do, people may still attack your preregistration and make you wonder if it was worth writing one in the first place. To combat this, I recommend using preregistrations more selfishly: use them to help plan your research and to document key decisions for your future (more forgetful) self. This allows you to ensure that your preregistrations are not a waste of time and may also increase the quality of your preregistrations by harnessing the benefits of intrinsic motivation on output quality (Cerasoli, Nicklin & Ford, 2014).

4.2.2 Generalizability

Conclusions drawn in this dissertation cannot be generalized past ***females*** smelling their ***male*** partner's body odor. Males were not well represented in this data (no males were included in Chapter 2; only 38 males were included in Chapter 3). Though the interaction between scent exposure and participants' sex was not significant (potentially due to the small sample), analysis of male participants alone did not yield a significant relationship between scent exposure and sleep (results can be seen in Appendix B, and male participant's sleep appears to be similar across the scent conditions). It is possible that the effect does not exist in males, or that we were not able to detect an effect due to the limited sample size. It is also possible that our manipulation was not strong enough for males (due to a combination of male's weaker sense of smell and female's weaker body odors; Doty, 1981; Brand & Millot, 2001). Given our small male sample, it is difficult to draw any conclusions for male participants. More research with larger samples will be necessary to discover if males are positively affected by exposure to the scent of their female partners.

In addition, only heterosexual relationships were represented in the current data. Examining homosexual couples would be of great interest as it would allow us to make distinctions between exposure to a male scent (versus a female scent) and between male smellers (versus female smellers). It is possible that male scents are especially calming to their romantic partners because males generally produce more intense and more easily-detectable scents. It is also possible that the influence of scent is more pronounced for females because females have a more acute sense of smell and are commonly more sensitive to emotional signals (Brody & Hall, 2000), making females better able to detect, learn, and/or react to their partner's scents. Studying different types of people and different relationships would undeniably result in a more complete understanding of how and for whom this effect functions in the real world.

Another notable limitation is the short length of romantic relationships represented in the current data. It is difficult to determine how long it takes for strong attachments to form (research indicates there is no clear point that usefully discriminates when people form strong attachments to their romantic partners; Heffernan, Fraley, Vicary & Brumbaugh, 2012). In an effort to select participants who had formed strong attachments to one another, relationships under three months were excluded, a cut-off that is in line with similar research (e.g. Granqvist et al., 2019 used 4 months). Even excluding relationships under 3 months, the data collected here was heavily biased toward newer relationships. In Chapter 2, the average relationship length was between 2-3 years, ranging from 4 months to 12 years, and in Chapter 3 the average relationship length was 2 years, ranging from 3 months to 10 years. It is possible that olfactory communication in longer-term relationships functions somewhat differently. For example, scents may become more easily recognized over time and memories of social support may be more strongly associated with a romantic partner over time. Future work will be needed to examine the effects reported here within more established relationships.

In addition to the absolute length of a romantic relationship, the depth of the attachment and overall supportiveness within the relationship are likely to influence the stress-buffering, and sleep-inducing, effects of a romantic partner's odor. In emerging relationships, attachment is often relatively unimportant (sexual desire can be a primary motivator; Birnbaum & Finkel, 2015). Thus, in emerging relationships, exposure to the scent of a partner may be more closely tied to activation of the mating system rather than the attachment system, and this could lead to somewhat different reactions to the scent of a romantic partner. When a relationship becomes more established, the importance of sexual desire often diminishes and attachment ramps up (Birnbaum & Finkel, 2015). Since attachment underlies the hypothesized calming effect of a partner's scent, more attached partners may display stronger effects. Consistent with this thinking, initial evidence in Appendix B suggests that people in longer relationships may derive a greater benefit from exposure to their partner's scent. This trend was not statistically significant (interaction between relationship length and scent exposure predicting sleep, p=.09); however, visual inspection indicates that the effect becomes more pronounced after a relationship exceeds one year. In order to fully explore this question, future research should examine additional data containing a wider range of relationship lengths and the extent to which relationship length (as well as other measures of relationship stage/attachment/support) moderate the effects of exposure to a partner's scent.

4.3 Future Directions

As in most research, the studies presented here generate more questions than they can answer. I will describe open questions related to *how* and *for whom* this effect may occur, and highlight how these results tie into broader theoretical frameworks such as attachment orientation and social baseline theory. In addition, I will discuss the possibility that this effect also exists in other types of close relationships and within different relational contexts.

4.3.1 How a Partner Can Impact Health

The magnitude of the negative impact of poor (or lack of) social relationships is comparable to high blood pressure, alcoholism, and sedentary lifestyle (Holt-Lunstad et al., 2010). Mortality risk is more than doubled in people with the lowest number of social ties (compared to those with the highest; Berkman & Syme, 1979). For people with many social ties, wounds even heal faster (Detillion et al., 2004). But despite decades of research indicating that social ties predict improvements in mental and physical health, we still do not know *how* they achieve this.

At a very basic level, social relationship partners can offer tangible, instrumental support, such as assets and resources (e.g. food and shelter). They can also offer encouragement to help us meet our goals, such as goals to adhere to healthy eating regimens or regular exercise schedules (e.g. Umberson et al., 2010). Another possibility is that the association between improved health and strong relationships occurs primarily because of the emotional support provided by relationship partners. Emotional support, for example, could buffer the threat perceived during a stressful event (Cohen, 2004). In truth, it is almost certainly the case that both instrumental support and stress buffering play a role in how relationship partners benefit health. These two types of support may separately contribute to health, and they may also interact. For instance, if a relationship partner has historically been a source of instrumental support, this person's mere presence (or even just their scent) may buffer stress partially due to the knowledge that tangible, instrumental support would be available if needed.

Evidence from several lines of research (including this dissertation) indicate that the stress experienced during a threating experience can be buffered by sensing the presence of a supportive partner. This dissertation focuses on the perception of a partner via the sense of smell; however, other lines of work have examined additional ways of perceiving a partner using other senses (e.g. touch, sight). For instance, simply holding the hand of loved one while experiencing threat improves mood and reduces activity in brain regions associated with emotional responding (Coan et al., 2006; Coan et al., 2017). In addition, Ditzen et al., (2007) found that receiving a massage from a romantic partner successfully buffered stress. Similar effects have been found for the sense of sight in isolation—simply viewing pictures of loved ones has been shown to effectively buffer stress reactivity (Master et al., 2009; Younger et al., 2010).

The final two human senses (taste and hearing) have not received as much empirical attention. Taste is not often associated with the perception of other people. With respect to hearing, research has shown that having a partner provide verbal support during a stressor does not effectively buffer stress responses for females (Kirschbaum et al., 1995; Ditzen et al., 2007). Since stress responses are reduced in the presence of a non-evaluative partner (who is blindfolded or in some other way unable to judge performance; Feeney & Kirkpatrick, 1997; Allen et al., 1991; Edens, Larkin & Abel, 1992), people may appreciate the presence of a loved one, but this positive effect may be tempered in some circumstance by fears of negative appraisal and evaluation. Although direct verbal communication with a partner may not always be helpful, perhaps hearing the sounds of a partner going about their day (e.g., singing in the shower or talking to a friend in the next room) could effectively buffer stress.

So far, I have discussed the smell of a partner as one of many ways that one might obtain the positive effects associated with the physical presence of a romantic partner. However, smell also distinguishes itself from other cues to a partner (such as their physical presence or touch) in two ways. First, the smell of a partner can be perceived largely unconsciously. Though many participants in our study were able to identify whether or not they had smelled their partner's scent, these odors appear to be processed on a largely subconscious level (Lundström & Olsson, 2010; Lübke & Pause, 2015). Especially when one is unconscious (such as during sleep), the scent of a partner represents a unique way to signal support bypassing conscious analysis. Second, exposure to a partner's scent is unlikely to trigger feelings of social evaluation. For example, a large literature indicates that a centerpiece of successful weight loss is self-monitoring—which includes regularly checking one's weight (Burke, Wang & Sevick, 2011). A partner's support during a stressful "weigh in" may be comforting; however, if the partner is able to view the number on the scale, they also represent a potential source of negative social evaluation. In this instance, exposure to a partner's odor instead of their touch or physical presence could offer the best of both worlds.

4.3.2 The Influence of Attachment Style

The health benefits of a romantic partner's odor are likely to be contingent upon the expectation that one's partner provides a source of safety or support. If so, then the effect of smelling a partner may vary depending on the extent to which those romantic relationships are perceived to be safe and supportive. Individual differences, such as the perceiver's attachment style, have the potential to moderate the effect of the partner's scent. Historically, people were categorized into different attachment styles. However, advances in measurement and theory have led most researchers to believe attachment styles within romantic relationships are better characterized in a continuous fashion along two dimensions: anxiety and avoidance (Shaver & Fraley, 2004). This results in four potential attachment styles: secure, preoccupied, dismissing-avoidant, and fearful-avoidant. Figure 4.1 depicts where each of these attachment styles is situated relative to the avoidance and anxiety dimensions. For both theoretical and practical reasons, some scholars simplify this by folding the two dimensions into a one dimensional space by averaging across anxiety and avoidance scores (e.g. Granqvist et al., 2019). This results in one dimension ranging from secure (low anxiety & low avoidance) to insecure (high anxiety & high avoidance).

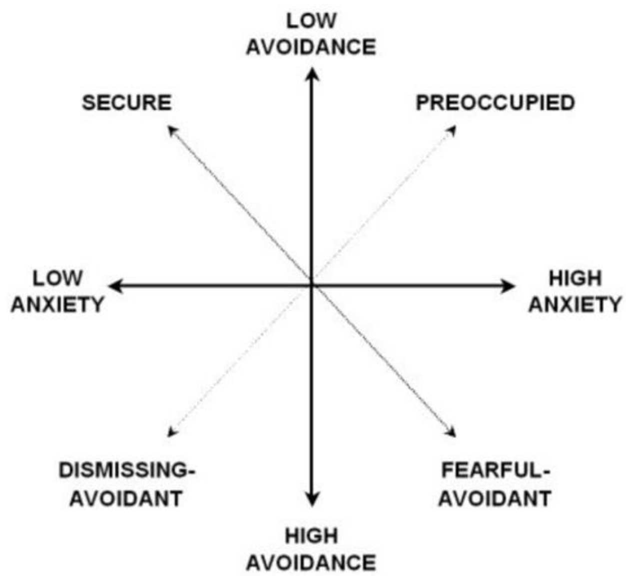

Figure 4.1 Model of adult attachment with two dimensions (redrawn form Shaver & Fraley, 2004).

Securely-attached individuals (those comfortable with closeness and dependency) receive more benefits from exposure to the physical presence of their loved ones than insecurely-attached individuals (Mikulincer & Shaver, 2016). And relatively securely-attached individuals display reduced stress responses in their partners' presence compared to insecurely-attached individuals (Carpenter & Kirkpartick, 1996). In general, in times of distress, it is believed that securely-attached individuals attempt to deal with their negative emotions and are comfortable seeking help when needed, while insecurely-attached individuals either do not rely on other people because of negative views of others (Dismissing-Avoidant), believe others would not respond well to them (Preoccupied), or avoid intimacy entirely (Fearful-Avoidant; Bartholomew & Horowitz, 1991).

If scent functions similarly to physical proximity, then exposure to a partner's scent may preferentially benefit securely-attached persons. Indeed, people with higher scores on both secure attachment and preoccupied attachment are more likely to intentionally smell a loved one's clothing (Streeter, 2009). In line with this natural behavior, people with higher levels of attachment security exposed to electric shocks while they smelled their romantic partner's odor displayed lower autonomic stress responses (Granqvist et al., 2019). Similarly, people with higher levels of attachment security exposed to a social stressor while they smelled their romantic partner's odor reported increased comfort and decreased anxiety (Streeter, 2009). In addition, preoccupied and fearful-avoidant attachment styles moderated negative emotional reactions: fearful people were negatively impacted by human scents (both a partners and a strangers) while preoccupied people strongly preferred the scent of their partner over a stranger. Since preoccupied people suffer from high anxiety about how they are viewed by others, the nonevaluative nature of odor may be especially beneficial for these persons. The findings reviewed here are in contrast to the data presented in chapter 2, which did not find any moderating effect of attachment style (see Appendix A); however, with only ninety-six participants spread across three groups, there is a strong risk of a false negative (Vadillo et al., 2016). Thus, my confidence in the absence of an attachment style effect in my data is not strong and this topic, as with many other topics, awaits additional research.

4.3.3 The Influence of Others on Vigilance Reduction

A second pair of eyes can greatly reduce the need for vigilance and the associated state of anxiety. Sharing vigilance efforts within groups has been widely studied in non-human animals (e.g. Beauchamp, 2015). However, less research has examined this phenomenon in humans.

Studies have found that humans in larger groups look up and scan their environment less, and group size is negatively correlated with the duration of these scans (e.g. Wirtz, Wawara, 1986; Barash, 1972). One study has experimentally manipulated group size and found that compared to when participants are alone, the mere presence of other people caused decreased vigilance (reduced time spent scanning peripheral targets; Gomes & Semin, 2020).

Provided that one can make use of the vigilance of those around them, people in groups can reduce their own vigilance efforts and allocate this time to other valuable activities. One interesting aspect of the study by Gomes and Semin (2020) is that participants' vigilance behavior decreased even though they were in a room with strangers and had no reason to expect cooperative behavior from these strangers. Humans are able to detect the emotions of a stranger, such as fear, through senses such as sound and odor (de Groot, Semin & Smeets, 2014). Thus, one can expect to receive some information about environmental threats from strangers without visual attention. Within a cooperative relationship, such as a romantic partnership, this effect may become even more pronounced. Many goals, such as safety, are shared between romantic couples, allowing members to expect active warnings from their partner if danger is detected. This added assurance may further reduce the individual effort necessary to meet the demands of the shared goals.

According to social baseline theory, people are able to outsource various neural activities associated with threat vigilance partially by altering what the brain classifies as "self" and expanding self to include close others (Coan & Sbarra, 2015). This theory is consistent with observations suggesting that the brain responds to threats directed at close others similarly to threats directed at the self (Beckes et al., 2013). If people construe romantic partners as extensions of the self, then scent cues of one's romantic partner (indicating their recent proximity) may cause the brain to temper its efforts toward vigilance, on the assumption that the romantic partner will fill in any attentional gaps. This reduced vigilance could lead to the types of outcomes—decreased stress reactions and improved sleep—documented in this dissertation.

4.3.4 Learned versus Innate

Throughout this work, the question has occasionally arisen of whether reactions to a romantic partner's scent are learned versus innate. It is currently unknown how much learning is involved in human olfactory communication (de Groot, Semin & Smeets, 2017). Humans readily learn to associate certain odors with emotional events. Five-year-old children given an impossible task while smelling a specific odor preformed more poorly on a different task while exposed to that same odor (Epple & Herz, 1999). Odor conditioning is not limited to unpleasant stimuli. For example, five-day-old infants who had been breastfed (and therefore learned to associate their mother's breastmilk with feeding and comfort) displayed reduced stress during a painful blood draw when exposed to their own mother's breastmilk compared to another woman's breastmilk (Nishitani et al., 2009). The scent of a supportive romantic partner could be similarly conditioned to promote calmness. In the same way that odor learning occurs for the state of fear (de Groot, Semin & Smeets, 2017), the odor of a romantic partner can be learned and associated with calmness: certain odorants produced by a romantic partner may be repeatedly present in similar supportive interactions with the partner, and this regular paring can forge an association between the chemical pattern of the romantic partner and the calming features of their physical presence.

However, it is also possible that some of the positive reactions toward a partner's scent are innate. Humans are attracted to certain body odors such as those from people with dissimilar immune profiles and lower levels of fluctuating asymmetry (Thornhill, Chapman & Gangestad, 2013; Wedekind & Furi, 1997). If people select partners based on these odor preferences, it is possible that they naturally prefer the scents of their romantic partner over a stranger's odor, and that the positive influence of their partner's scent is based on an innate preference for this scent. A complete analysis of learned versus innate reactions to social odorants is past the scope of this chapter and has been discussed at length elsewhere (e.g. Wyatt, 2014; Doty 2010; de Groot, Semin & Smeets, 2017); however, both learned and innate reactions may play some role in the positive influence of a romantic partner's scent. While the current data cannot disentangle these two possibilities, arranged marriages offer an interesting avenue for future exploration. Arranged marriages are common in much of the world and are generally chosen for reasons unrelated to any preferences the bride and groom may have. Thus, one way to tease apart the two possibilities described above would be to conduct studies on the effect of a partner's scent among people in arranged marriages and compare the effect sizes to those found among people in love marriages.

4.3.5 Interactions Between Different Categories of Learned Association

Future research might also productively explore how some of the lines of inquiry reviewed in Chapter 1 might interact. The three types of olfactory associations identified in chapter 1 (Table 1.1) were: associations between human body odors and 1) transient emotional states, 2) personal characteristics such as age, and 3) the presence of specific individuals of special relevance to the self. An interesting interaction may occur between the first and third categories of learned association mentioned above. Much of the research on transient emotional states has focused on odor-based inferences about the emotions of strangers. Very little is known about odor-based inferences about emotions of intimate others. People may differentially respond to fear-related odor cues, depending on the nature of their relationship to the fearful individual. For instance, exposure to the scent of a stranger experiencing fear elicits increases in vigilance (e.g. Chen, Katdare, & Lucas, 2006; de Groot et al., 2012) but is not likely to elicit approach (if anything, it may be preferable to increase distance from the source of the threat). However, if a scent not only communicates fear, but also indicates that the odor originated from one's child, exposure to this scent may elicit a very different response. Due to the importance of protecting one's offspring, enhanced vigilance and search behaviors might be expected. In addition, since it is easier to protect someone when you are near them, additional approach-oriented responses may be observed that would not occur if the scent came from a stranger.

Similarly, research on the scent of sickness has also focused exclusively on scents from strangers. Responses to sickness related odor cues may also depend on the nature of one's relationship to the sick individual. People encountering odor cues of sickness from loved ones may display approach-oriented responses, as opposed to the avoidance-oriented responses elicited by the smell of sickness from a stranger. Future research exposing people to scents of their loved ones experiencing fear or sickness could productively explore these possibilities.

4.3.6 Other Potential Directions for Future Inquiry

Research on a familiar person's scent has mainly focused on romantic partners and mother/child dyads. But other important relationships exist (e.g., between friends, co-workers, and siblings). People in those relationships can identify each other using scent, and these scents can have predictable inferential consequences. For instance, the scent of a friend is perceived to be more pleasant and less intense than the scent of a stranger (Lundström et al, 2008). Since many different kinds of relationships exist, and relationships with unrelated individuals can become so emotionally close that they become psychologically similar to familial relationships (Ackerman, Kenrick & Schaller, 2007). It would be fruitful for future research to explore the effects of exposure to a wider range of close relationships. We may well discover that reactions to familiar scents are sometimes negative, such as with exposure to the scent of an abusive parent or a competitive sibling.

Just as a romantic partner is usually associated with one set of relational schema (e.g. comfort), a different social partner may be associated with a different set of relational schema (e.g. a parent being associated with responsibility). The relative availability and accessibility of relational schema can determine a person's psychological reaction in a particular situation (Baldwin et al, 1996), and cues to a specific person may trigger relational schema associated with that person. For example, imagine a drunk teenager leaves a party and gets into the car he borrowed from his dad. The car smells like his father. When the teenager sits down in the driver's seat, the relational schema associated with his father regarding responsibility may be activated and influence his decision about whether to drive. In this way, smelling a familiar lingering scent might have a wide-range of cognitive and behavioral consequences. While these ideas are currently completely speculative, they could form the basis of an intriguing new line of work.

As social scent communication research comes out of its infancy, it will be important to take the findings about scent based social judgements out of tightly-controlled laboratory settings and begin integrate these signals into the complex social environment that exists in the real world. Imagine someone experiencing anxiety in the morning (during a dissertation defense, for example) who then meets a friend in the afternoon (to have celebratory drinks!). Would the fear scent retained in her clothing raise her friend's defense responses? Or would her smile and relaxed demeanor counteract these anxiety odor signals? Some recent research has begun to examine odor cues alongside visual cues of fear and sickness and found that both odor and visual cues appear to uniquely inform appraisals (de Groot, Semin & Smeets, 2014; Regenbogen et al., 2017). This direction in olfaction research can hopefully allow us to understand the ways in which body odor influences interpersonal appraisals within the complexity of the real world.

4.3.7 Conclusion

Social scents are instrumental at the beginning of life, when they help babies find their mothers, and throughout adulthood when they influence who we like and how we feel. The loss of olfactory functioning has even been associated with increased mortality above and beyond its relationship to other diseases, perhaps due to its role in social functioning (Ekström et al., 2017). A deeper understanding of the sense of smell—especially placed within pre-existing social relationships—represents an exciting area for future research and has the potential to reveal unidentified forces that shape our thoughts, decisions, behavior and health.

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Appendices

Appendix A - Supplemental Information for Chapter 2

A.1 Participant Recruitment and Demographics

The following information offers further details on recruitment of study participants and demographics of the final sample. One hundred and thirty-four couples were recruited at a large university in North America through the university's "Human Subject Pool" and a paid studies list to participate in a study about "interpersonal relationships." The study was approved by the university's behavioral research ethics board. *A priori* exclusion criteria were applied to exclude participants who had medical conditions which could lead to unstable health (e.g., chronic or acute illnesses), or due to circumstances which may influence key dependent measures (e.g. inability to smell, use of hormonal birth control; see Table A.1 for a complete set of eligibility criteria).

One hundred and thirty-four couples participated. Thirty-eight couples did not complete the study, or completed the study inaccurately and were not included in the final dataset (associated cortisol samples, if any, were not sent out for analysis): eighteen women failed to obtain a clear indication of their ovulation status, four women choose to end the study during the stress test (two in the stranger condition, one in the unworn condition, one in the partner condition), ten couples did not complete all experimental sessions, two couples broke up, one couple became long-distance, and three were excluded due to experimenter errors affecting the protocol/timing of events during the women's TSST session. Random assignment to scent exposure took place after the first session, and scent exposure groups did not significantly differ on demographic information or relationship measures (e.g., age, relationship satisfaction, length of relationship, see Table A.2). The ninety-six remaining participants were analyzed.

All participants provided informed consent. For their participation, 66% of participants were compensated monetarily in proportion to their time commitment (males $20 CAD, females $40 CAD), and the remaining participants received extra credit in a psychology course.

Table A.1 ***Inclusion criteria for men and women***

	Criteria	Women	Men
1.	Were in a heterosexual romantic relationship for over three month	X	X
2.	Lived in the Vancouver area	X	X
3.	Did not smoke cigarettes	X	
4.	Were without a history of chronic medical or psychiatric disorders	X	
5.	No current or previous psychiatric treatment in the past 6 months	X	
6.	Did not have anosmia (inability to smell)	X	
7.	Self-rated ability to smell above "1" on 5 point scale (1= Extremely Below Average; 5= Extremely Above Average)	X	
8.	Natural menstrual cycle (did not use hormonal birth control)	X	
9.	Regular menstrual cycle (between 21 and 35 days)	X	
10.	No use of recreational "hard" drugs in the last 3 months	X	
11.	No use of antihistamines or decongestant nasal sprays	X	
12.	No use of cortisone, steroid injections, topical steroid creams or hydrocortisone creams	X	
13.	No use of other prescription medications screened on an individual basis for influence on heart rate or cortisol	X	

Table A.2 ***Mean (standard deviation) and statistical significance of ANOVAs predicting demographic information from scent condition***

Demographic Variable	Partner	Stranger	Unworn	*p*-value of difference
Relationship Satisfaction	6.27 (.43)	5.99 (.56)	6.14 (.51)	.10
Avoidant Attachment Style	2.38 (.93)	2.52 (.81)	2.39 (1.05)	.80
Ambivalent Attachment Style	2.44 (1.13)	2.31 (.85)	2.21 (1.06)	.66
Woman's Age	21.22 (3.37)	21.66 (4.67)	21.63 (4.16)	.89
Man's Age	22.50 (4.11)	22.84 (6.48)	23.06 (5.18)	.91
Length of Relationship	27.98 (29.45)	29.63 (25.39)	27.06 (24.70)	.93
Days per Week Spent with Partner	4.72 (1.88)	5.02 (1.92)	5.14 (1.79)	.65
Brief Fear of Negative Evaluation Scale	37.61 (11.13)	38.33 (9.20)	37.66 (11.01)	.97

Note**. Relationship Satisfaction is measured using the Perceived Relationship Quality Component (Fletcher, Simpson & Thomas, 2000). Attachment style is measured using the AAQ (Simpson, Rholes & Phillips, 1996). Brief Fear of Negative Evaluation Scale is used as described in Leary (1983).**

A.2 Heart Rate Analyses

The following section offers details on the methods and data analyses on heart rate data collected in association with this research. Directly after participants provided baseline measures of cortisol and perceived stress, they were fitted with a Polar RS800CX Heart Rate Monitor belt and watch. Participants were asked to stand for five minutes to obtain baseline heart rate. Thereafter, heart rate was measured continuously throughout the experiment. Five intervals of interest were defined (Baseline, Preparation, Speech, Math, Recovery), each lasting five minutes. Participants set a heart rate marker at the beginning of each of the intervals, and the average heart rate for the following five minutes was computed.

We modified the method of heart rate measurement during the experiment to obtain more fine-grained data. For the first twenty-four participants, heart rate was recorded only every five seconds. Thereafter, RR interval data (time period between each heart beat) was collected. Heart rate data was first error-corrected[13]. Frequent equipment errors resulted in a substantial portion of heart rate data to be unreliable or lost. Data were excluded if two-thirds of the total experimental

[13] Error correction was done differently in five second data versus RR interval data. For five second data spikes (or dips) of more than thirty bpm within twenty seconds were replaced with the average HR from the thirty seconds before and thirty seconds after the spike (or dip). Thirty percent of the five second data was analysed by another rater and interrater reliability was practically perfect (r=0.99). RR interval data was corrected for aberrant beats and errors using the automated filtering feature set to low and with the minimum protection zone set at the default level of six beats per minute.

time was not comprised of clean data (i.e. free from large spikes, unlikely patterns, and unrealistic heart rate values). Two independent raters who were blind to participant's condition rated all heart rate data on suitability for analysis using the two-thirds exclusion rule. Raters disagreed on five participants (interrater reliability r =.83). Differences were addressed and agreed upon by raters. We chose this exclusion method to eliminate clearly unreliable data while still retaining a majority of participants for analysis; it should however be noted that, for many participants, data still included a substantial portion (up to one third) of unreliable data.

The remaining sample size was $n = 71$ (24 unworn, 24 stranger, 23 partner). Data were analyzed using a two-way ANOVA with repeated measures [scent exposure (partner, stranger or unworn) X time (repeated factor with 5 values)]. Heart rate changed over the course of the experiment as expected (significant main effect of time, $F(2.61, 177.44) = 88.61$, $p < .001$), indicating that the stress test influenced participant's heart rate. The main effect of scent exposure was not significant ($F(2, 68) = 0.62$, $p = .54$), nor was there a significant interaction between time and scent exposure ($F(5.22, 177.44) = 1.29$, $p = .27$). Our study thus provides no evidence for differences in in heart rate due to scent exposure. It should be noted that we also had lower power to detect effects, due to the sample being reduced from ninty-six (in the perceived stress and cortisol analyses reported in the main text) to seventy-one.

A.3 Relationship Between Perceived Stress and Cortisol

Perceived stress and physiological stress reactions are linked, with the underlying pathway between the two proposed to include a cognitive evaluation of the stressor that subsequently activates physiological systems such as the HPA axis (Feldman, Conforti & Weidenfeld, 1995; Herman, Ostrander, Mueller & Fiqueiredo, 2005). In our data, partial correlations revealed that anticipatory perceived stress (a minute prior to TSST) was related to cortisol at all three stress stages (partial correlations between anticipatory perceived stress and anticipatory, peak, and recovery cortisol are .29, .28, .24, respectively; p's < .02; partial correlations are controlling for baseline subjective stress and baseline cortisol). Perceived stress at the later (post-stress) time points and cortisol were not significantly correlated (p's >.28).

Due to this relationship between anticipatory perceived stress and cortisol, we further investigated whether perceived stress mediated the effect of scent exposure on cortisol reactions. Stranger and partner condition were compared because these two conditions were significantly different on both perceived stress and cortisol. A scent exposure variable was created with participants exposed to their partner's scent coded '0' and a stranger's scent coded '1'. Analyses were conducted using the PROCESS macro within SPSS (Hayes, 2013) using 1,000 bootstrap samples to compute indirect effects and 95% CIs. Three mediation analyses were conducted (controlling for baseline cortisol and perceived stress), which predicted the three cortisol phases (Y; anticipatory, peak, and recovery) from scent exposure (X), mediated by anticipatory perceived stress (M).

Anticipatory perceived stress was a significant mediator of both anticipatory and peak cortisol reactions (indirect effects = 1.38 (SE = 0.97), 95% CI = [0.01, 3.83]; 3.06 (SE = 1.97), 95% CI = [0.20, 7.93]; respectively), but not cortisol recovery (indirect effect =1.10 (SE = 0.81), 95% CI = [-0.02, 3.07]). These results suggest that initial (anticipatory) perceived stress and cortisol are related, and that the elevated initial perceived stress experienced by people exposed to a stranger's scent (versus their partner's scent) may at least partially explain differences in the cortisol responses between those two groups.

A.4 ANOVA - Actual Scent Exposure and Belief about Scent Exposure

The following section explores the question of whether actual scent exposure, belief about scent exposure, or both drove the observed effects. It is worth noting that the methods used in this study were not designed to answer this research question (e.g., belief about shirt identity was not manipulated, and our power to detect effects in subgroups is low). However, due to the interest value of this question, data are examined in an exploratory fashion.

At the end of the experiment, women were asked if they believed the scent that they smelled belonged to their partner (see Table A.3 for summary of responses by condition). Women were able to guess, at above chance levels (75% accuracy), whether they were exposed to their partner's scent; this resulted in high collinearity between actual scent exposure and belief about scent exposure.

Table A.3 ***Participants' beliefs about the scent they were exposed to by scent exposure***

Scent Exposure	Total (n)	Believed partner's shirt (n)	Believed NOT partner's shirt (n)
Partner	32	20	12
Stranger	32	8	24
Unworn	32	4	28

Actual Scent Exposure. In order to determine if scent exposure alone influenced stress reactivity, we examined the subset of 64 women who believed they did not smell their partner's shirt (12-Partner, 24-Stranger, 28-Unworn). We used this analytical strategy to eliminate the issue of collinearity between actual and believed scent exposure (i.e., these 64 women all held the same belief about the scent to which they were exposed). This group was chosen because it had a larger sample size than the alternative choice (women who believed they had smelled their partner's shirt).

Perceived Stress. In the subset of women who believed that they did not smell their partner's shirt, there was a marginally significant interaction between time and scent exposure when predicting perceived stress ($F(5.36, 163.48) = 2.08$, $p = .066$, $\eta_2 = 0.06$, Figure A.1). This effect size is similar to that of the entire sample ($\eta_2 = 0.05$) and offers initial suggestive evidence that actual exposure to a partner's scent alone is sufficient to reduce perceived stress (a similar and significant interaction was found using HLM analysis, available below).

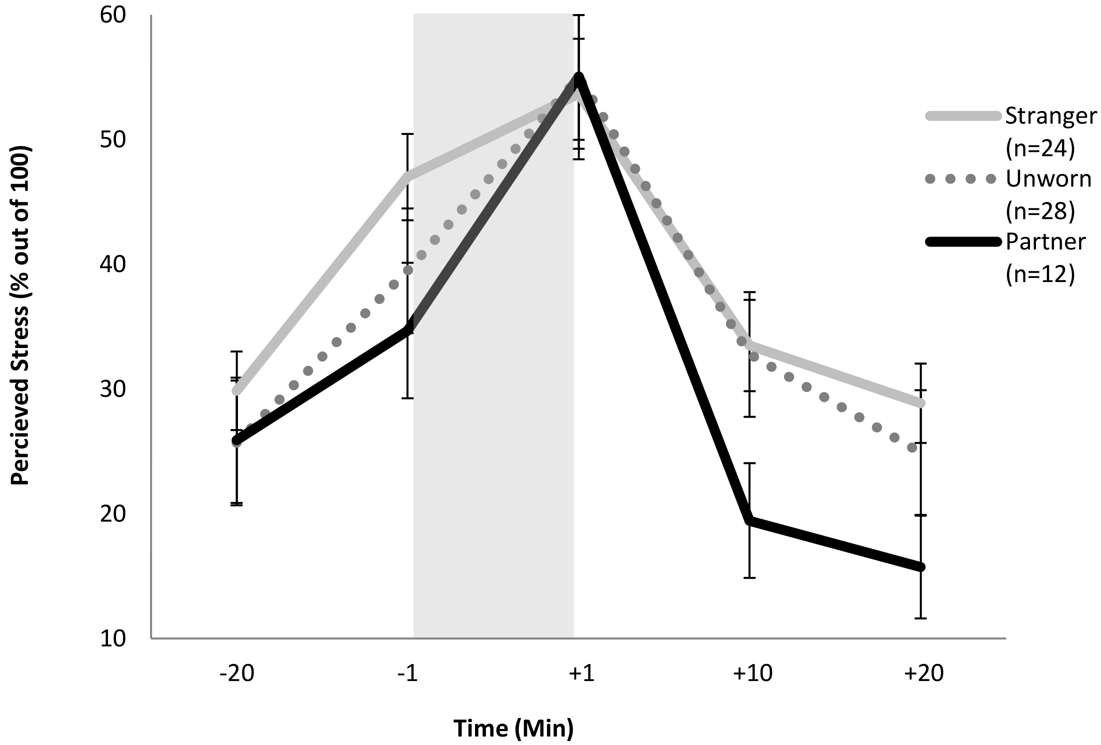

Figure A.1 ***Perceived stress in participants who did not believe they were exposed to their partner's scent separated by scent exposure.***

Shaded section indicates stress induction (TSST). Error bars represent ±1 SEM.

To follow up on this interaction, we conducted three regression analyses controlling for baseline perceived stress and comparing scent exposure at three phases of stress (anticipatory, peak, and recovery). In the anticipatory phase, women exposed to their partner's scent reported marginally lower stress than those exposed to a stranger's scent $p = .07$; unworn non-significant, $p = .33$; Table A.4). In the anticipatory phase, there were no significant differences (p's > .63; Table A.4). In the recovery phase, women exposed to their partner's scent reported significantly lower stress compared to both stranger and unworn scents ($p = .01$ & 006; Table A.4). This pattern of the data is similar to what was found in the entire sample and provides initial suggestive evidence that exposure to a partner's scent alone is sufficient to reduce perceived stress, specifically during the recovery period. This outcome indicates that (even in women who were not aware they had smelled their partner's scent) perceived stress is reduced by exposure to a partner's scent.

Table A.4 ***Perceived stress predicted from scent exposure in women who believed that they did not smell their partner's shirt***

	B	***β***	***t***	***p***
Anticipatory				
Partner versus Stranger	9.51	.25	1.86	.068
Partner versus Unworn	4.93	.13	0.99	.326
Peak				
Partner versus Stranger	-3.48	-.08	-0.47	.638
Partner versus Unworn	0.03	.00	0.01	.996
Recovery				
Partner versus Stranger	11.10	.35	2.68	**.010**
Partner versus Unworn	11.38	.36	2.83	**.006**

Note**. Anticipatory = -1, Peak = +1, Recovery = mean of +10 and +20. Scent exposure dummy coded (partner = 0; other scent exposures = 1). Bold items indicate p < .05.**

Cortisol. No significant interaction between time and scent exposure was detected, $F(212.29, 122.05) = 1.74$, $p = .17$, $\eta_2 = 0.05$. Thus, for women who did not believe they were exposed to their partner's scent, our analysis offers no evidence that scent exposure affects cortisol.

Belief about Scent Exposure. In order to determine if women's *belief alone* about the scent they smelled contributed to their stress reactivity, we examined only the subset of 32 women who were exposed to their partner's scent (20-Believed partner scent, 12-Did not believe). Women in the partner group were all exposed to their partner's scent, thus eliminating the issue of collinearity between actual and believed scent exposure. Partner group was chosen over the other options (stranger, unworn) to maximize our power to detect an effect, because women in the partner group were most evenly divided in their beliefs about scent exposure (Table A.3).

Perceived Stress. There was no significant interaction between time and scent exposure when predicting perceived stress, $F(2.44, 207.94) = 0.70$, $p = .53$, $\eta_2 = 0.02$. Thus, in women exposed to their partner's shirt, our analysis offers no evidence that beliefs about scent exposure impact perceived stress.

Cortisol. A marginally significant interaction between time and belief emerged when predicting cortisol ($F(1.60, 47.93) = 3.24$, $p = .059$, $\eta_2 = 0.10$, Figure A.2). In women exposed to their partner's scent, believing they were exposed to their partner's scent resulted in reduced cortisol reactions (a similar and significant interaction was found using HLM analysis, available below). This outcome provides initial suggestive evidence that merely believing that one has smelled a partner's shirt can lower cortisol responses to a stressor.

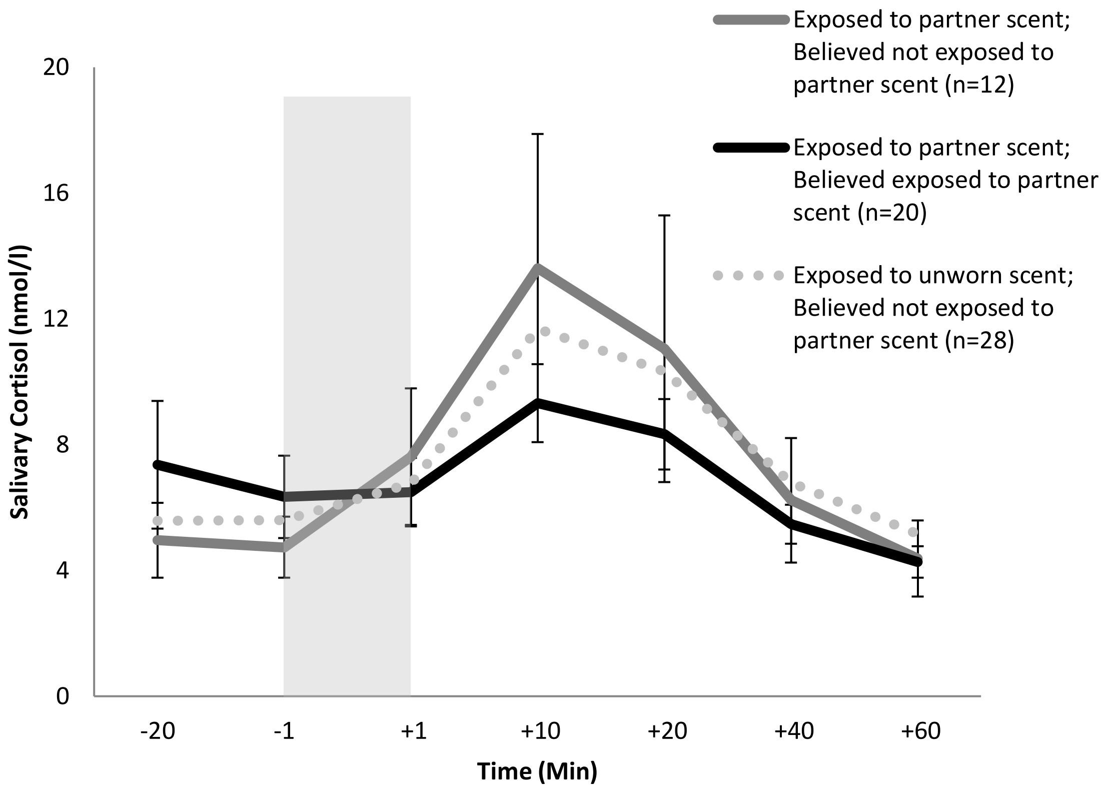

Figure A.*2 Cortisol levels in participants exposed to their partner's scent separated by belief about scent exposure*

Shaded section indicates stress induction (TSST). Error bars represent ±1 SEM. For comparison, a dashed line has been added to represent data from women who were exposed to an unworn scent and believed they were not exposed to their partner's scent.

A.5 HLM - Actual Scent Exposure and Belief about Scent Exposure

Actual Scent Exposure. We conducted additional HLM analyses to support the conclusions from the ANOVA analyses reported above on the subset of sixty-four women who believed they did not smell their partner's shirt, testing whether scent exposure alone influenced stress reactivity.

Perceived Stress. In an analysis using ANOVA, there was a marginally significant interaction between time and scent exposure when predicting perceived stress ($F(5.36, 163.48) = 2.08$, $p = .066$, $\eta_2 = 0.06$, Figure A.1). Here we report a parallel analysis using a hierarchical linear model. The model predicted perceived stress from time and condition, with the five stress-ratings grouped within participant. Perceived stress changed over the course of the experiment as expected (significant main effect of time, $\chi_2(4) = 193.96$, $p < .001$), indicating that the stress test influenced participant's stress reactions. There was a non-significant main effect of scent exposure ($\chi_2(2) = 2.73$, $p = .26$) which—of most relevance for our hypothesis—was qualified by a significant interaction between time and scent exposure, $\chi_2(8) = 15.45$, $p = .017$ (see Figure A.1).

In order to follow up on the significant interaction, three time contrasts were set comparing baseline stress to the three phases of stress [anticipatory (1-minute pre-stress induction), peak (1 minute post-stress induction) and recovery (mean of 10 & 20 minutes post-stress induction)]. Two condition contrasts were set, comparing the partner condition to the stranger and unworn conditions.

Results revealed that during the stress recovery, women exposed to their partner's scent reported significantly less perceived stress than those exposed to both a stranger's or unworn scent ($p < .05$, Table A.5). Scent condition did not predict perceived stress at any other time point comparison (Table A.5). Consistent with the results from the ANOVA, provide converging evidence that exposure to a partner's scent alone (in the absence of belief) is sufficient to reduce perceived stress, specifically during the recovery period.

Table A.5 ***Perceived stress predicted from scent condition in women who believed they had not smelled their partner's shirt***

	Subjective Stress		
	b	***t***	***p***
Partner versus Stranger			
Anticipatory	8.33	1.50	.140
Peak	-5.35	-0.95	.343
Recovery	9.62	1.97	**.050**
Partner versus Unworn			
Anticipatory	5.00	0.91	.364
Peak	0.13	0.02	.980
Recovery	11.46	2.41	**.017**

Note. ***N*** **= 320 (64 participants x 5 Stress Scores). Degrees of freedom = 247. Condition dummy coded with partner = 0 (all other conditions = 1 and were compared to partner condition). Time dummy with base = 0 (all other time points = 1 and were compared to base). Unstandardized regression coefficients are presented. Bold items indicate p < .05.**

Cortisol. In an analysis using ANOVA above, there was no significant interaction between time and scent exposure, $F(212.29, 122.05) = 1.74$, $p = .17$, $\eta_2 = 0.05$. Here we report a parallel analysis using a hierarchical linear model. The model predicted cortisol from time and condition, with the seven cortisol measurements grouped within participant. Cortisol changed over the course of the experiment as expected (significant main effect of time, $\chi_2(4) = 141.39$, $p < .001$), indicating that the stress test influenced participant's cortisol. There was a non-significant main effect of scent exposure ($\chi_2(2) = 0.96$, $p = .62$) which—of most relevance for our hypothesis—was qualified by a significant interaction between time and scent exposure, $\chi_2(8) = 18.01$, $p = .006$.

To follow up on the significant interaction, three time contrasts were set comparing baseline stress to the three phases of stress [anticipatory stress (1 minute pre-stress induction), peak stress (mean of ten & twenty minutes after the end of the stressor) and stress recovery (mean of forty & sixty minutes after the end of the stressor)]. Two condition contrasts were set, comparing the partner condition to the stranger and unworn conditions.

Results revealed no significant effects of comparison to partner condition (Table A.6). These results offer no support for the cortisol-buffering effect of partner scent in the absence of belief. The significant interaction was likely due to significant differences between the stranger and unworn conditions (which are not tested here).

Table A.6 ***Cortisol predicted from scent condition in women who did not believe they had smelled their partner's shirt***

	Subjective Stress		
	b	***t***	***p***
Partner versus Stranger			
Anticipatory	1.47	0.62	.533
Peak	2.74	1.16	.246
Recovery	2.59	1.10	.273
Partner versus Unworn			
Anticipatory	-0.91	-0.39	.694
Peak	-4.27	-1.85	.064
Recovery	-1.19	-0.52	.605

Note. N **= 448 (64 participants x 7 Stress Scores). Degrees of freedom = 375. Condition dummy coded with partner = 0 (all other conditions = 1 and were compared to partner condition). Time dummy with base = 0 (all other time points = 1 and were compared to base). Unstandardized regression coefficients are presented. Bold items indicate p < .05.**

Belief about Scent Exposure. We conducted additional HLM analyses to support the conclusions reported in ANOVA above on the subset of thirty-two women who were exposed to their partner's scent regarding if women's *belief alone* about the scent they smelled contributed to their stress reactivity.

Perceived Stress. In an analysis using ANOVA above, there was no significant interaction between time and scent exposure when predicting perceived stress, $F(2.44, 207.94)$ =

0.70, $p = .53$, $\eta^2 = 0.02$. Here we report a parallel analysis using a hierarchical linear model. The model predicted perceived stress from time and condition, with the five stress ratings grouped within participant. Perceived stress changed over the course of the experiment as expected (significant main effect of time, $\chi^2(4) = 135.10$, $p < .001$), indicating that the stress test influenced participant's stress reactions. There was a non-significant main effect of scent exposure ($\chi^2(2) = 0.09$, $p = .76$) which—of most relevance for our hypothesis—indicated no interaction between time and scent exposure, $\chi^2(8) = 2.61$, $p = .46$. Similar to the ANOVA reported in main text, this analysis offers no evidence that perceived stress is affected by beliefs about scent exposure.

Cortisol. In an analysis using ANOVA above, there was a marginally significant interaction between time and belief emerged when predicting cortisol ($F(1.60, 47.93) = 3.24$, $p = .059$, $\eta^2 = 0.10$, Figure A.2). Here we report a similar analysis using a hierarchical linear model. The model predicted cortisol from time and condition, with the seven cortisol measurements grouped within participant. Cortisol changed over the course of the experiment as expected (significant main effect of time, $\chi^2(4) = 41.92$, $p < .001$), indicating that the stress test influenced participant's cortisol. There was a non-significant main effect of scent exposure ($\chi^2(2) = 0.74$, $p = .39$) which—of most relevance for our hypothesis—was qualified by a significant interaction between time and scent exposure, $\chi^2(8) = 17.97$, $p < .001$. This interaction supports the results from the ANOVA analysis, suggesting that women who believed they were exposed to their partner's scent produced less cortisol compared to those who believed they were not exposed to their partner's scent (Figure A.2).

A.6 ANOVA - Women Who Identified if They Had Smelled Their Partner's Shirt

In the discussion section of the main text, we consider the increased external validity of examining only participants who accurately guess the origin of the scents they encounter. Here we report the results of ANOVA analyses on this subset of participants (HLM analyses are reported directly below). Participants were analyzed if they correctly identified whether or not the scent they were exposed was that of their partner or not, 72 women did so (28 unworn, 24 stranger, 20 partner; Table A.3).

Perceived Stress. Similar to the entire sample, a significant interaction emerged between time and scent exposure when predicting perceived stress, $F(5.41, 186.62) = 2.66$, $p = .02$, $\eta_2 =$ 0.07. To determine where conditions differed, we conducted three regression analyses controlling for baseline perceived stress and comparing scent exposure at the three phases of stress (anticipatory, peak, and recovery). During the anticipatory phase, women exposed to their partner's shirt reported significantly lower perceived stress than those exposed to a stranger's scent and marginally lower than those exposed to no scent ($p = .006$ & .07, respectively; Table A.7). During peak stress, there were no significant differences (p's > .25; Table A.7). In the recovery phase, women exposed to their partner's shirt reported marginally significantly lower perceived stress compared to those exposed to a stranger's scent and significantly lower perceived stress compared to those exposed to an unworn scent ($p = .08$ & .05, respectively; Table A.7). This pattern of data was similar to the one observed in the entire sample, providing evidence that when women accurately guessed their scent condition, partner scent continues to have a stress buffering effect on perceptions of stress.

Table A.7 ***Perceived stress predicted from scent exposure in women who correctly identified if they had smelled their partner's shirt***

	B	***β***	***t***	***p***
Anticipatory				
Partner versus Stranger	11.81	.30	2.81	**.006**
Partner versus Unworn	7.37	.19	1.82	.073
Peak				
Partner versus Stranger	-6.94	-.16	-1.14	.258
Partner versus Unworn	-3.46	-.08	-0.59	.556
Recovery				
Partner versus Stranger	6.20	.19	1.80	.077
Partner versus Unworn	6.61	.21	1.99	**.050**

Note. **Anticipatory = -1, Peak = +1, Recovery = mean of +10 and +20. Scent exposure dummy coded (partner = 0; other scent exposures = 1). Bold items indicate p < .05.**

Cortisol. Similar to the entire sample, a significant interaction between time and belief emerged when predicting cortisol (F(3.13, 108.03) = 4.85, p = .005, η_2 = 0.12, Figure 2.4 in main text). In contrast to the entire sample, in this subsample women in the partner condition produced *lower* levels of cortisol compared to women exposed a stranger's scent and to no scent. The partner vs. stranger comparison was significant for all time points (p's < .01; Table A.8) and the partner vs. unworn comparison was not significant at any time point (*p*'s < .21; Table A.8). However, an alternative HLM analysis (shown below) indicated that women in the partner condition produced significantly lower levels of cortisol compared to women exposed no scent.

Table A.8 ***Cortisol predicted from scent exposure in women who correctly identified if they had smelled their partner's shirt***

	B	***β***	***t***	***p***
Anticipatory				
Partner versus Stranger	5.55	.34	3.07	**.003**
Partner versus Unworn	1.90	.12	1.11	.270
Peak				
Partner versus Stranger	10.41	.41	3.09	**.003**
Partner versus Unworn	3.68	.15	1.15	.254
Recovery				
Partner versus Stranger	4.68	.39	2.96	**.004**
Partner versus Unworn	1.88	.16	1.25	.215

Note. **Anticipatory = -1, Peak = +1, Recovery = mean of +10 and +20. Scent exposure dummy coded (partner = 0; other scent exposures = 1). Bold items indicate p < .05.**

A.7 HLM - Women Who Identified if They Had Smelled Their Partner's Shirt

We conducted additional HLM analyses to support the conclusions from the ANOVA analyses reported above on the subset of seventy-two women who correctly identified whether they had smelled their partner's shirt, testing whether scent exposure combined with correct belief about scent exposure influenced stress reactivity.

Perceived Stress. HLM was used to predict perceived stress from time and condition, with the five stress ratings grouped within participant. Perceived stress changed over the course of the experiment as expected (significant main effect of time, $\chi_2(4) = 220.99$, $p < .001$), indicating that the stress test influenced participant's stress reactions. There was a non-significant main effect of scent exposure ($\chi_2(2) = 2.53$, $p = .28$) which—of most relevance for our hypothesis—was qualified by a significant interaction between time and scent exposure, $\chi_2(8) = 20.01$, $p = .003$. This result is comparable to results found in the above ANOVA analysis.

In order to follow up on the significant interaction, three time contrasts were set comparing baseline stress to the three phases of stress [anticipatory (a minute pre-stress induction), peak (a minute post-stress induction) and recovery (mean of ten & twenty minutes post-stress induction)]. Two condition contrasts were set, comparing the partner condition to the stranger and unworn conditions.

Results revealed that, during the anticipatory stress phase, women exposed to their partner's scent reported significantly less perceived stress than those exposed to a stranger's scent ($p = .030$, Table A.9). Scent condition did not predict perceived stress at any other comparison (Table A.9). These results provide converging evidence that when women accurately guessed their scent condition, partner scent continues to have a stress buffering effect on perceptions of stress.

Table A.9 ***Perceived stress predicted from scent condition in women who correctly identified whether or not they had smelled their partner's shirt***

	Subjective Stress		
	b	***t***	***p***
Partner versus Stranger			
Anticipatory	10.54	2.18	**.030**
Peak	-9.22	-1.90	.058
Recovery	4.57	1.09	.277
Partner versus Unworn			
Anticipatory	7.21	1.54	.125
Peak	-3.74	-0.80	.425
Recovery	6.41	1.60	.115

Note. **N = 360 (72 participants x 5 Stress Scores). Degrees of freedom = 279. Condition dummy coded with partner = 0 (all other conditions = 1 and were compared to partner condition). Time dummy with Base = 0 (all other time points = 1 and were compared to base). Unstandardized regression coefficients are presented. Bold items indicate p < .05.**

Cortisol. HLM was used to predict cortisol from time and condition, with the seven cortisol measurements grouped within participant. Cortisol changed over the course of the experiment as expected (significant main effect of time, $\chi_2(4) = 125.95$, $p < .001$), indicating that the stress test influenced participant's cortisol. There was a non-significant main effect of scent exposure ($\chi^2(2) = 1.87$, $p = .39$) which—of most relevance for our hypothesis—was qualified by a significant interaction between time and scent exposure, $\chi^2(8) = 45.89$, $p < .001$ (Figure 2.4 in main text).

To follow up on the significant interaction, three time contrasts were set comparing baseline stress to the three phases of stress [anticipatory stress (a minute pre-stress induction), peak stress (mean of ten & twenty minutes after the end of the stressor) and stress recovery (mean of forty & sixty minutes after the end of the stressor)]. Two condition contrasts were set, comparing the partner condition to the stranger and unworn conditions.

Results revealed that women exposed to their partner's scent produced significantly less cortisol than those exposed to a stranger's scent at all time comparisons ($p < .03$, Table A.10). And, most interestingly, participants exposed to their partner's scent produced significantly less cortisol than those exposed to an unworn scent during peak stress ($p = .02$, Table A.10).

Table A.10 ***Cortisol predicted from scent condition in women in women who correctly identified whether or not they had smelled their partner's shirt***

	Subjective Stress		
	b	***t***	***p***
Partner versus Stranger			
Anticipatory	3.93	2.21	**.028**
Peak	10.98	6.15	**.000**
Recovery	6.67	3.74	**.000**
Partner versus Unworn			
Anticipatory	1.56	0.90	.367
Peak	3.97	2.30	**.022**
Recovery	2.89	1.68	.094

Note. **N = 504 (72 participants x 7 Stress Scores). Degrees of freedom = 423. Condition dummy coded with partner = 0 (all other conditions = 1 and were compared to partner condition). Time dummy with Base = 0 (all other time points = 1 and were compared to base). Unstandardized regression coefficients are presented. Bold items indicate p < .05.**

In summary, for women who accurately identified whether or not they had smelled their partner's shirt, 1) stranger scents lead to more cortisol production than both partner and unworn scents, and 2) women may experience a cortisol-buffering response from exposure to the scent of their partner compared to both stranger and unworn conditions. This result provides exploratory support for the possibility that the combination of exposure to your partner's shirt and believing you smelled your partner's shirt buffers cortisol reactions in stressful situations.

Appendix B - Supplemental Information for Chapter 3

B.1 Exclusion Criteria

Table B.1. ***Exclusion criteria***

	Criteria	Sleepers	Scent Donors
1.	Living outside the Vancouver area	X	X
2.	Cigarette smoker	X	
3.	History of chronic medical/psychiatric disorders	X	
4.	Psychiatric treatment within past 6 months	X	
5.	Anosmia (inability to smell)	X	
6.	Self-rated ability to smell of "1" on 5 point scale (1=Extremely Below Average)	X	
7.	Use of "hard" drugs within past 3 months	X	
8.	Use of prescription medications screened on an individual basis for influence on sleep	X	

B.2 Means and T-tests

Means and paired sample t-tests are presented separately for each sample below. Means represent the average of the two nights spent with a specific shirt. Two-tailed tests are used unless otherwise specified (when preregistration specified the use of one-tailed tests). Analyses presented below are all as preregistered, with one exception (see Footnote 1).

Sample 1

Forty heterosexual couples participated. After exclusions (Appendix B), data from thirty-seven women were analyzed ($M_{\text{relationship length}}$=22.34 months, *SD*=15.46; M_{age}=20.59 years, *SD*=2.31). Women primarily identified as Asian (62%, including South Asian and Indian) or Caucasian (30%).

Women's sleep efficiency was higher on nights spent with a partner's shirt than an unworn shirt (91.61% and 84.67%, respectively). This difference was statistically significant; $t(36)=3.39$, $p=.002$.

One woman was given the wrong sleep diary and is not included in the perceived sleep quality analyses. Women's perceived sleep quality was not significantly different on nights spent with a partner's shirt versus an unworn shirt (4.59 and 4.68, respectively; $t(35)=0.51$, $p=.61$).

Sample 2

In Sample 2 we sought to replicate these results of Sample 1 and expand the examination to men. Forty-nine couples participated. After exclusions (Appendix B), Forty women and thirty-eight men remained ($M_{\text{relationship length}}$=23.01 months, *SD*=19.02; M_{age}=20.71 years, *SD*=2.81). Participants primarily identified as Asian (48%, including South Asian and Indian) or Caucasian (33%).

Overall Results

Sleep efficiency was higher on nights spent with a partner's shirt than an unworn shirt (86.92% and 85.45%, respectively). This increase did not reach conventional standards of statistical significance; $t(77)=1.347$, $p=.091$, one-tailed.

Perceived sleep quality was higher on nights spent with a partner's shirt than an unworn shirt (4.73 and 4.59, respectively). This increase was not statistically significant; $t(77)=1.31$, $p=.196$.

Results – Women

Women's sleep efficiency was higher on nights spent with a partner's shirt than an unworn shirt (88.42% and 85.78%, respectively). This increase did not reach statistical significance; $t(39)=1.34$, $p=.094$,, one-tailed.

Women's perceived sleep quality was higher on nights spent with a partner's shirt than an unworn shirt (4.85 and 4.52, respectively). This increase was statistically significant; $t(39)=2.36$, $p=.023$.

Results – Men Only

Men's sleep efficiency was higher on nights spent with a partner's shirt than an unworn shirt (85.34% and 85.10%, respectively). This increase did not reach statistical significance; $t(37)=0.28$, $p=.78$.

Men's perceived sleep quality was lower on nights spent with a partner's shirt than an unworn shirt (4.60 and 4.67, respectively). This difference was not statistically significant, $t(37)=0.49$, $p=.63$.

Sample 3

In Sample 3 we compared a partner's scent to a gender-matched stranger's scent. However, because data collection for Sample 3 began before Sample 2 was analyzed, the same (potentially underpowered) sample size of forty was used.

Forty-five couples participated. As in Sample 1, Sample 3 used women as sleepers and men as scent donors. After exclusions (Appendix B), forty women remained ($M_{\text{relationship length}}$=24.53 months, *SD*=27.01; M_{age}=20.98 years, *SD*=4.57).[14] Women primarily identified as Asian (65%, including South Asian and Indian) or Caucasian (23%).

Women's sleep efficiency was higher on nights spent with a partner's shirt than an unworn shirt (86.88% and 85.78%, respectively); this difference was not statistically significant; $t(39)=0.82$, $p=.21$, one-tailed.

Women's perceived sleep quality was higher on nights spent with a partner's shirt than an unworn shirt (4.88 and 4.53, respectively). This difference was statistically significant; $t(39)=2.03$, $p=.049$.

14 Our preregistration stated that "We are not likely to have missing data. However, if data is missing from the sleep watch for any night, that participant will be excluded from analyses." We made this statement because we anticipated that missing data would indicate non-compliance with study protocols. We did not, however, anticipate sleep watches failing on some nights at no fault of the participant. Thus, we decided to retain four participants with one night of missing data (i.e., for whom paired sample t-tests were still possible) who would have been excluded using the original decision rule. Exclusion of these four participants does not significantly alter our results or their inferential implications. In fact, their exclusion decreases the mean difference between partner and stranger nights.

B.3 Exploratory Analysis on Pleasantness

We used data from Sample 3 (where a stranger's scent was used as a control condition) to explore the effect of exposure to a stranger's scent. A MLM predicting sleep efficiency from scent, perceived scent pleasantness (grand mean centered), and their interaction, showed a significant interaction between scent and pleasantness (*b*=3.21, *SE*=1.10, *p*=0.005, *95% CI* [1.12; 5.52]). Simple slope analyses revealed that pleasantness negatively predicted sleep efficiency on nights spent with the stranger's scent (*b*=-2.31, *SE*=0.82, *p*=.007, *95% CI* [-0.71; -4.00]), but not partner's scent (*b*=0.90, *SE*=0.72, *p*=.22, *95% CI* [-0.48; 2.25]), indicating that scents from particularly pleasant-smelling strangers may inhibit sleep. Though exploratory, these analyses suggest that a stranger's scent may create its own manipulation, making it a problematic control condition.

B.4 Number of Exclusions by Sample

Table B.2. ***Number of exclusions by sample***

	Sample 1	Sample 2 Women	Sample 2 Men	Sample 3
Slept in the same bed as partner	2	2	2	
Relationship ended	1			
Did not adhere to cigarette and marijuana restrictions during scent collection		1	1	
Did not follow protocol (either did not sleep with partner's shirt on any night or could not remember order)		2	1	3
Did not fit eligibility requirements regarding smoking and/or drug usage[15]			5	
Sleep watch malfunction resulting in no data in at least one scent condition		4	2	2

15 We screened for smoking and drug use prior to data collection for women but neglected to do so for men.

B.5 Exploratory Tests of Moderation

Forward Stepping Sleep Efficiency. To detect potential moderators, additional MLMs were computed using a forward stepwise approach as recommended for MLM by Nezlek (2008). We began with the initial model predicting sleep from scent and added predictors one at a time, along with their interactions with scent, testing for significance at each step. If the interaction was not significant (at a relaxed threshold of p=.10), the interaction was removed and the model was tested again. Predictors that were not statistically significant at p=.10 in any model were removed from the model before new predictors were added. This forward stepwise approach kept the number of predictors in a model low in order to avoid surpassing the carrying capacity of the data (which happens especially quickly in MLM to the nonlinear increase in parameters; Nezlek, 2008). Results using a backwards stepwise approach were also examined (in which all predictors were included at once and nonsignificant ones were removed in a stepwise fashion; see below). This alternate method had no effect on the direction or significance of the effect of scent on either sleep outcome variable.

First, variables measured at Level 1 were added one by one along with their interactions with scent (daily perceived stress, scent duration & weeknight, in that order). Scent Duration was effect coded (-1=first night; 1=second night). The study spanned from Monday to Thursday night, so Monday and Wednesday were always the first night with a new scent (-1) and Tuesday and Thursday the second night (1). Perceived stress was cluster centered within person. Weeknight (scored as 1-4 representing Monday through Thursday) was centered by subtracting by the mean (2.5).

Next, variables measured at Level 2 were added one by one along with their interactions with scent (In the following order: Control Scent, Avoidant & Ambivalent Attachment, Sex, Relationship Length, Relationship Quality, and Order). Avoidant & Ambivalent Attachment were added together within one model. All continuous control variables measured at the person level (level 2) were centered around their grand mean (these include: Relationship Quality, Relationship Length, Avoidant Attachment style, and Ambivalent Attachment style). The dummy coded variable *control scent* indicates which control scent a participant slept with (unworn shirt=0; stranger's shirt=1). The mean perceived stress level for each person across all four days was included as a measure of *average perceived stress* (Level 2) and grand mean centered. The final model (Results in Table B.13) had five predictors: Scent, Scent Duration, Sex, Scent Duration x Scent & Sex x Scent.

Tables for each model tested are displayed in Tables B.3-B.12. If the interaction was not significant at p = .10, the interaction was removed and the model was tested again. We do not show results with the interaction removed, except in the one instance when that model yielded a new significant predictor (weeknight predicting perceived sleep quality).

Table B.3. ***Two-Level HLM Predicting Sleep Efficiency from Scent Type, Daily Perceived Stress and their interaction***

	b (SE)	***p***	***95% CI***
Scent	2.60 *(0.77)*	< .001	1.14, 4.07
Daily Perceived Stress	0.24 *(0.67)*	.72	-1.06, 1.56
Scent * Daily Perceived Stress	0.23 *(0.93)*	.81	-1.61, 1.96

Table B.4. ***Two-Level HLM adding Scent Duration***

	b (SE)	***p***	***95% CI***
Scent	2.48 *(0.69)*	< .001	1.16, 3.81
Scent Duration	-2.12 *(0.48)*	< .001	-3.10, -1.25
Scent * Scent Duration	2.24 *(0.69)*	.001	0.90, 3.66

Table B.5. ***Two-Level HLM adding Weeknight***

	b (SE)	***p***	***95% CI***
Scent	2.52 *(0.76)*	.001	1.02, 4.07
Scent Duration	-2.45 *(0.59)*	< .001	-3.61, -1.29
Weeknight	0.72 *(0.75)*	.34	-0.77, 2.23
Scent * Scent Duration	2.61 *(0.82)*	.002	-0.94, 4.29
Scent * Weeknight	-0.79 *(1.04)*	.45	-2.91, 1.39

Table B.6. ***Two-Level HLM adding Control Scent***

	b (SE)	***p***	***95% CI***
Scent	3.05 *(0.88)*	< .001	1.21, 4.72
Scent Duration	-2.10 *(0.45)*	< .001	-3.01, -1.24
Control Scent	0.32 *(1.71)*	0.85	-2.82, 3.64
Scent * Scent Duration	2.22 *(0.64)*	< .001	1.02, 3.53
Scent * Control Scent	-1.92 *(1.75)*	0.27	-5.52, 1.43

Table B.7. ***Two-Level HLM adding Attachment Style***

	b (SE)	***p***	***95% CI***
Scent	2.56 *(0.76)*	.001	1.10, 4.04
Scent Duration	-2.09 *(0.45)*	< .001	-3.00, 1.17
Ambivalent	0.16 *(0.79)*	0.84	-1.41, 1.57
Avoidant	0.68 *(1.13)*	0.55	-1.44, 3.01
Scent * Scent Duration	2.21 *(0.64)*	< .001	-1.03, 3.41
Scent * Ambivalent	0.62 *(0.81)*	0.44	-0.87, 2.20
Scent * Avoidant	-1.13 *(1.16)*	0.33	-3.35, 0.97

Table B.8. ***Two-Level HLM adding Sex***

	b (SE)	***p***	***95% CI***
Scent	3.33 *(0.87)*	< .001	1.66, 5.14
Scent Duration	-2.09 *(0.45)*	< .001	-3.02, -1.21
Sex	-0.37 *(1.74)*	0.83	-3.62, 3.00
Scent * Scent Duration	2.21 *(0.64)*	< .001	0.90, 3.52
Scent * Sex	-3.10 *(1.76)*	0.081	-6.51, 0.21

Table B.9. ***Two-Level HLM adding Relationship Length***

	b (SE)	***p***	***95% CI***
Scent	3.37 *(0.87)*	< .001	1.64, 5.10
Scent Duration	-2.09 *(0.45)*	< .001	-3.01, 1.24
Sex	-0.33 *(1.74)*	0.85	-3.83, 3.34
Relationship Length	-0.03 *(0.04)*	0.45	-0.10, 0.04
Scent * Scent Duration	-2.22 *(0.64)*	< .001	-0.98, 3.48
Scent * Sex	-3.18 *(1.75)*	0.07	-6.77, 0.45
Scent * Relationship Length	0.06 *(0.04)*	0.11	-0.01, 0.14

Table B.10. ***Two-Level HLM adding Relationship Quality***

	b (SE)	***p***	***95% CI***
Scent	3.31 *(0.87)*	< .001	1.62, 5.00
Scent Duration	-2.09 *(0.45)*	< .001	-2.95, -1.22
Sex	-0.64 *(1.74)*	0.71	-4.12, 2.47
Relationship Quality	-1.91 *(1.26)*	0.13	-4.40, 0.35
Scent * Scent Duration	-2.20 *(0.64)*	< .001	1.00, 3.44
Scent * Sex	-2.99 *(1.78)*	0.09	-6.43, 0.65
Scent * Relationship Quality	0.78 *(1.29)*	0.55	-1.68, 3.50

Table B.11. ***Two-Level HLM adding Order***

	b (SE)	***p***	***95% CI***
Scent	4.06 *(1.15)*	< .001	1.74, 6.23
Scent Duration	-2.09 *(0.45)*	< .001	-2.96, -1.24
Sex	-0.26 *(1.74)*	0.88	-3.35, 3.11
Order	1.43 *(1.50)*	0.34	-1.70, 4.21
Scent * Scent Duration	2.21 *(0.64)*	< .001	0.98, 3.48
Scent * Sex	-3.21 *(1.77)*	0.07	-6.66, 0.08
Scent * Order	-1.50 *(1.52)*	0.33	-4.39, 1.64

Table B.12. ***Two-Level HLM adding Average Perceived Stress***

	b (SE)	***p***	***95% CI***
Scent	3.31 *(0.87)*	< .001	1.69, 5.07
Scent Duration	-2.09 *(0.45)*	< .001	-3.00, -1.22
Sex	-0.56 *(1.74)*	0.75	-3.86, 2.64
Average Perceived Stress	-0.99 *(0.74)*	0.18	-2.36, 0.42
Scent * Scent Duration	2.21 *(0.64)*	< .001	1.02, 3.48
Scent * Sex	-3.02 *(1.77)*	0.09	-6.44, 0.38
Scent * Average Perceived Stress	0.33 *(0.76)*	0.66	-1.18, 1.78

Table B.13. *Two-Level HLM final model with interactions*

	b (SE)	***p***	***95% CI***
Scent	3.33 *(0.87)*	<.001	1.71, 5.00
Scent Duration	-0.37 *(1.74)*	.83	-3.93, 2.99
Sex	-2.09 *(0.45)*	<.001	-3.00, -1.25
Scent * Scent Duration	-3.10 *(1.76)*	.081	-6.38, 0.42
Scent * Sex	2.21 *(0.64)*	<.001	0.89, 3.42

This analysis highlighted two potential moderators of the relationship between scent and sleep efficiency (interactions between scent duration and scent, and sex and scent). The interaction between scent and scent duration was examined on an exploratory basis. Sleep efficiency was relatively stable across the two nights exposed to a partner's scent (First Night *M*=87.97, *SD*=7.39; Second Night *M*=88.22, *SD*=7.76). However, sleep efficiency decreased on the second night spent away from a partner's scent (First Night *M*=87.81, *SD*=7.98; Second Night *M*=83.57, *SD*=13.75). Thus, participants sleep got worse on the second night when they were exposed to no scent. Speculatively, this result could indicate that a longer separation from one's partner negatively impacts sleep. It is equally possible that a partner's scent initially lingers in participant's bedrooms.

A non-significant interaction between scent and sex also emerged. Even though the interaction did not reach the traditional standard of statistical significance (p = .081), we explored it further by conducting post-hoc simple slope analyses. These analyses revealed that scent predicted sleep efficiency among women (b=3.32, *SE*=0.87, p<.001, *95% CI* [1.55; 4.96]), but not men (b=0.23, *SE*=1.53, p=.88, *95% CI* [-3.39; 3.86]; Figure B.1). This result could indicate that the beneficial effect of exposure to a partner's scent are specific to females, or it could indicate a failure in the strength of the manipulation (i.e., that female participants' scent was not strong enough to be detected by males).

Given that our study was not designed to test these effects, and because these moderation analyses may be underpowered, it is worth emphasizing that future research will be required to confirm these findings.

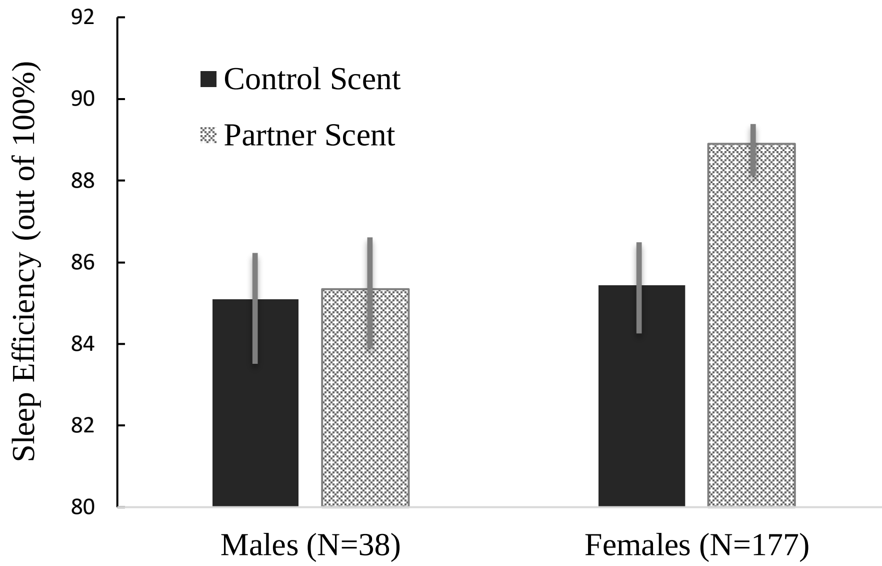

Figure B.1. **Sleep efficiency for males and females by scent type. Error bars represent ±1 SEM.**

Forward Stepping Perceived Sleep Quality. An identical method was used to test for moderation in perceived sleep quality. No moderators emerged. Results of models tested are shown below.

Table B.14. ***Two- Level HLM Predicting Perceived Sleep Quality from Scent Type, Daily Perceived Stress and their interactions***

	b ***(SE)***	***p***	***95% CI***
Scent	0.19 *(0.08)*	.024	0.02, 0.36
Daily Perceived Stress	-0.26 *(0.04)*	< .001	-0.41, 0.13
Scent * Daily *Perceived* Stress	0.12 *(0.10)*	.23	-0.07, 0.34

Table B.15. ***Two-Level HLM adding Scent Duration***

	b *(SE)*	***p***	***95% CI***
Scent	0.19 *(0.08)*	.017	0.04, 0.33
Daily Perceived Stress	-0.19 *(0.04)*	< .001	-0.27; -0.09
Scent Duration	0.00 *(0.06)*	.99	-0.11, 0.11
Scent * Scent Duration	-0.04 *(0.08)*	.64	-0.18, 0.12

Table B.16. ***Two-Level HLM adding Weeknight***

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.030	0.02, 0.34
Daily Perceived Stress	-0.18 *(0.05)*	< .001	-0.27, -0.10
Weeknight	0.08 *(0.06)*	.18	-0.03, 0.20
Scent * Weeknight	-0.03 *(0.09)*	.76	-0.20, 0.16

Table B.17. ***Two-Level HLM removing Weeknight * Scent interaction***

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.030	0.02, 0.34
Daily *Perceived* Stress	-0.19 *(0.05)*	< .001	-0.27, -0.09
Weeknight	0.06 *(0.04)*	.078	-0.01, 0.14

Table B.18. ***Two-Level HLM adding Control Scent***

	b (SE)	***p***	***95% CI***
Scent	0.11 *(0.09)*	.25	-0.08, 0.29
Daily Perceived Stress	-0.18 *(0.05)*	< .001	-0.27, 0.09
Weeknight	0.07 *(0.04)*	.068	-0.01, 0.14
Control Scent	-0.09 *(0.16)*	.56	-0.40, 0.21
Scent * Control Scent	0.26 *(0.19)*	.16	-0.08, 0.62

Table B.19. ***Two-Level HLM adding Attachment Style***

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.030	0.03, 0.34
Daily Perceived Stress	-0.18 *(0.05)*	< .001	-0.27, -0.10
Weeknight	0.06 *(0.04)*	.088	-0.01, 0.13
Ambivalent	-0.10 *(0.07)*	.19	-0.23, 0.05
Avoidant	0.05 *(0.11)*	.63	-0.14, 0.25
Scent * Ambivalent	0.05 *(0.09)*	.53	-0.12, 0.22
Scent * Avoidant	-0.19 *(0.12)*	.12	-0.43, 0.05

Table B.20. ***Two-Level HLM adding Sex***

	b (SE)	***p***	***95% CI***
Scent	0.25 *(0.09)*	.009	0.06, 0.42
Daily Perceived Stress	-0.18 *(0.05)*	< .001	-0.28, -0.09
Weeknight	0.07 *(0.04)*	.064	-0.01, 0.14
Sex	0.09 *(0.16)*	.57	-0.21, 0.40
Scent * Sex	-0.28 *(0.19)*	.15	-0.62, 0.10

Table B.21. ***Two-Level HLM adding Relationship Length***

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.031	0.02, 0.35
Daily Perceived Stress	-0.19 *(0.05)*	< .001	-0.28, -0.10
Weeknight	0.06 *(0.04)*	.077	-0.01, 0.14
Relationship Length	-0.00 *(0.00)*	.69	-0.01, 0.00
Scent * Relationship Length	-0.00 *(0.00)*	.76	-0.01, 0.01

Table B.22. *Two-Level HLM adding Relationship Quality*

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.029	0.02, 0.34
Daily Perceived Stress	-0.19 *(0.05)*	< .001	-0.28, -0.09
Weeknight	-0.06 *(0.04)*	.10	-0.01, 0.14
Relationship Quality	0.00 *(0.12)*	.99	-0.24, 0.24
Scent * Relationship Quality	0.14 *(0.14)*	.33	-0.12, 0.40

Table B.23. ***Two-Level HLM adding Order***

	b (SE)	***p***	***95% CI***
Scent	0.43 *(0.19)*	.023	0.07, 0.80
Daily Perceived Stress	-0.19 *(0.05)*	< .001	-0.27, -0.09
Weeknight	-0.03 *(0.08)*	.66	-0.19, 0.11
Order	0.25 *(0.20)*	.22	-0.14, 0.69
Scent * Order	-0.50 *(0.34)*	.14	-1.19, 0.15

Table B.24. ***Two-Level HLM adding Average Perceived Stress***

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.031	0.02, 0.35
Daily Perceived Stress	-0.18 *(0.05)*	< .001	-0.28, -0.10
Weeknight	0.06 *(0.04)*	.079	-0.01, 0.14
Average Perceived Stress	-0.03 *(0.07)*	.70	-0.16, 0.11
Scent * Average Perceived Stress	0.03 *(0.08)*	.70	-0.13, 0.19

Table B.25. ***Two-Level HLM final model with interactions***

	b (SE)	***p***	***95% CI***
Scent	0.18 *(0.08)*	.030	0.02, 0.33
Daily Perceived Stress	0.06 *(0.04)*	.078	-0.01, 0.14
Weeknight	-0.19 *(0.05)*	< .001	-0.27, -0.10

This model is identical to the one reported in the main manuscript because no interactions were significant.

Backward Stepping Sleep Efficiency. All variables, and their interactions with scent, were added simultaneously to the model (these include: Scent Duration, Perceived Stress, Control Scent, Sex, Avoidant & Ambivalent Attachment, Relationship Length, Relationship Quality, and Order). Weeknight is omitted because it is a combination of Scent Duration and Order, and is therefore is not linearly independent of these two other predictors. All three could not be included in the same model. Models omitting a different variable and including weeknight do not result in weeknight being a significant predictor. All measures over p = .10 were removed one by one (unless they were part of an interaction remaining in the model). Results from the final model containing predictors significant at p < .10 are displayed below. These results highlight two additional potential moderating variables: Relationship Length and Control Scent.

Table B.26. ***Two-Level HLM predicting Sleep Efficiency***

	b *(SE)*	***p***	***95% CI***
Scent	4.52 *(1.06)*	< .001	2.43, 6.42
Scent Duration	-2.10 *(0.45)*	< .001	-2.98, -1.18
Sex	-0.23 *(1.86)*	0.90	-3.87, 3.57
Relationship Length	-0.03 *(0.04)*	0.45	-0.10, 0.05
Control Scent	0.29 *(1.82)*	0.87	-3.31, 3.95
Scent * Scent Duration	2.23 *(0.64)*	< .001	0.96, 3.48
Scent * Sex	-4.33 *(1.85)*	0.02	-8.17, -0.83
Scent * Relationship Length	0.06 *(0.04)*	0.09	-0.02, 0.14
Scent * Control Scent	-3.42 *(1.82)*	0.06	-7.03, 0.30

The marginal interaction involving control scent indicates that the improvement in sleep efficiency on nights spent with a partner's scent may not be the equal across the two types of control scent (stranger vs. unworn shirt). From analyses described in the Appendix B, we know the direction of this difference: people exposed to the unworn shirt (instead of a stranger's shirt) have a more pronounced increase in sleep efficiency when sleeping with their partner's scent.

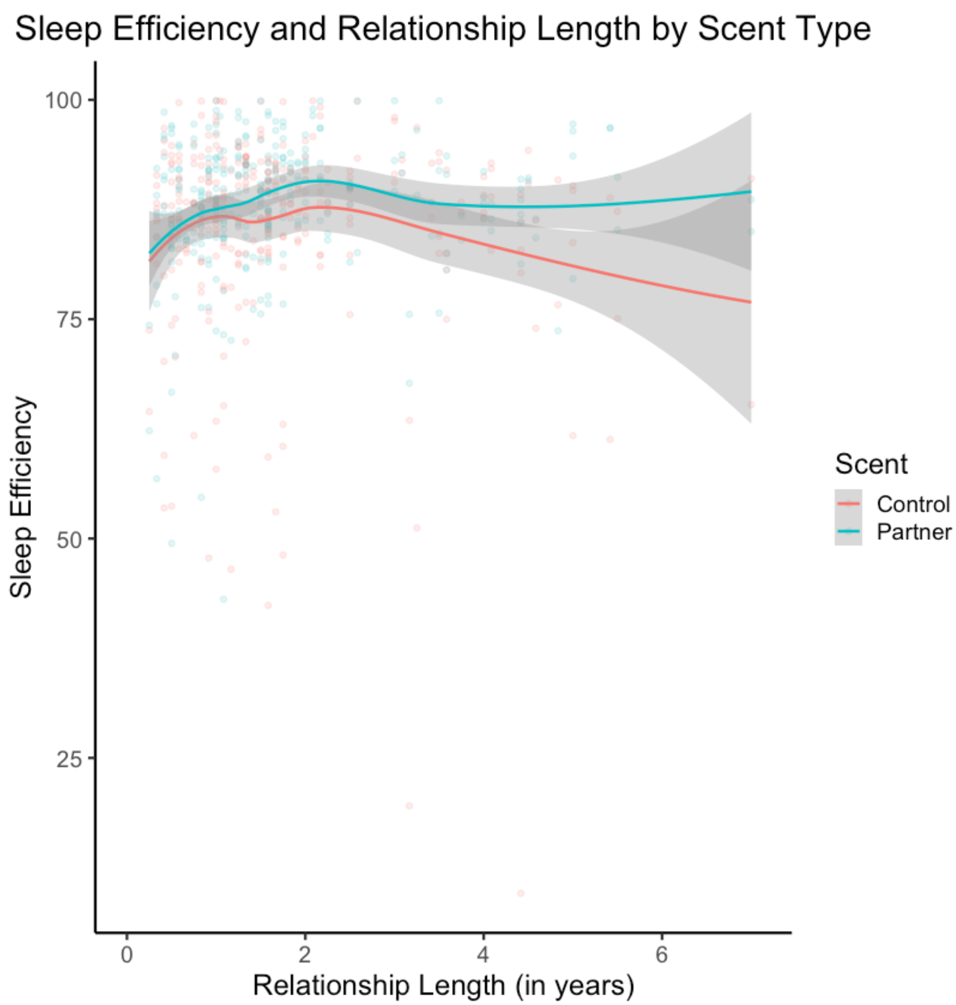

Figure B.2. **Sleep efficiency across relationship length separated by scent type.**

The marginal interaction involving Relationship Length indicates that the improvement in sleep efficiency on nights spent with a partner's scent may be moderated by how long the couple has been in a relationship. The graph above sheds light on the direction of the interaction. Since all participants are contributing data to both the control and the partner scent groups, the meaningful difference in the graph above is the distance between the red and blue lines. For relationships less than one year long, there are very small differences between sleep on nights spent with control and partner scents. However, in longer relationships (between 1 and 7 years) there is a more pronounced difference. Participants with relationships longer than 7.1 years are outliers on relationship length (more than 3 SDs above the mean in our sample of 1.94 years; four people were outliers by this definition) and are not shown on the graph. These results provide initial evidence that people in longer relationships may have a stronger positive effect from exposure to their partner's scent.

While these exploratory results are thought provoking, they should be interpreted with caution. Many potential moderators were tested, and the results outlined above were neither large nor statistically significant. They are presented to aid in hypothesis generation for future studies.

B.6 Backward Stepping Perceived Sleep Quality.

The same procedure backwards-stepping procedure as above (including all predictors simultaneously and removing significant predictors one by one) was followed for sleep quality.

Table B.27. ***Two Level HLM predicting Perceived Sleep Quality***

	b (SE)	***p***	***95% CI***
Scent	0.36 *(0.11)*	.002	0.13, 0.58
Order	0.19 *(0.14)*	.19	-0.10, 0.46
Daily Perceived Stress	-0.19 *(0.05)*	< .001	-0.28, -0.10
Scent * Order	-0.37 *(0.16)*	.025	-0.69, -0.06

While this alternate method does not change the effect of scent on sleep, it does highlight an interaction between order and scent (Table B.27). Simple slopes analyses indicate that scent predicts sleep efficiency among those who first smelled the control scent and then their partner's scent (b = 0.36, SE = 0.11, p = .002, 95% CI [0.13; 0.58]), but not among those who slept with the scents in the opposite order (*b* = -0.09, *SE* = 0.12, *p* = .44, 95% CI [-0.33; 0.14]). However, since this interaction was not anticipated, the finding is best regarded with caution.

B.7 Final Model Including all Predictors Simultaneously

The following two tables display results from models including control variables described in the main manuscript. No interactions are included. These results represent interim models which were used to arrive at the final models presented in the main manuscript.

Table B.28. ***Two-Level HLM predicting Sleep Efficiency from scent and all control variables simultaneously (no interactions).***

	b *(SE)*	***p***	***95% CI***
Scent	2.66 *(0.78)*	< .001	1.12, 4.32
Weeknight	-0.25 *(0.34)*	.47	-0.90, 0.52
Daily Perceived Stress	0.31 *(0.40)*	.44	-0.46, 1.08
Average Perceived Stress	-0.76 *(0.49)*	.13	-1.76, 0.14
Sex	-3.67 *(1.20)*	.003	-5.96, -1.35
Relationship Length	0.02 *(0.02)*	.52	-0.03, 0.06
Relationship Quality	-0.97 *(0.92)*	.29	-2.82, 0.86
Ambivalent Attachment	0.37 *(0.53)*	.49	-0.68, 1.38
Avoidant Attachment	-0.01 *(0.78)*	.99	-1.52, 1.57
Control Scent	-1.80 *(1.19)*	.13	-4.08, 0.59
Order	-0.17 *(1.04)*	.87	-2.16, 1.92

Table B.29. ***Two-Level HLM predicting Perceived Sleep Quality from scent and all control variables simultaneously (no interactions).***

	b *(SE)*	***p***	***95% CI***
Scent	0.18 *(0.08)*	.031	0.02, 0.33
Weeknight	0.06 *(0.04)*	.079	-0.01, 0.13
Daily Perceived Stress	-0.18 *(0.05)*	< .001	-0.27, -0.09
Average Perceived Stress	0.00 *(0.06)*	.96	-0.11, 0.12
Sex	-0.06 *(0.14)*	.70	-0.32, 0.22
Relationship Length	-0.00 *(0.00)*	.34	-0.01, 0.00
Relationship Quality	-0.01 *(0.11)*	.93	-0.23, 0.21
Ambivalent Attachment	-0.08 *(0.06)*	.19	-0.21, 0.04
Avoidant Attachment	-0.05 *(0.09)*	.62	-0.23, 0.14
Control Scent	-0.01 *(0.14)*	.94	-0.27, 0.27
Order	-0.00 *(0.12)*	.97	-0.24, 0.23

B.8 Three-Level Model (Couple at Level Three)

Initial three-level model

Level 1 (night): $\text{Sleep}_{tij} = b_{0ij} + b_{1ij}(\text{Scent}_{tij}) + e_{tij}$

Level 2 (person): $b_{0ij} = \gamma_{00j} + u_{0ij}$

$b_{1ij} = \gamma_{10j} + u_{1ij}$

Level 3 (couple): $\gamma_{00j} = \beta_{000} + r_{00j}$

Sleep Efficiency. The couple level ICC was 0.00, indicating that 0% of the variance in sleep efficiency can be attributed to the couple level. The initial three-level model (using equations described above) indicated that scent type was a significant predictor of sleep efficiency (b = 2.58, SE = 0.76, p < .001, *95% CI* [1.10; 4.05]), and when rounded to the second decimal place this result is identical to the result from the two-level model reported in the main manuscript. To control for other variables and detect potential moderators, the identical series of multilevel models were performed predicting sleep from scent and other control variables. These variables and their interaction with scent were added in a stepwise fashion (using the method described in the main paper). When rounded to the second decimal place, these results are identical those using a two-level model reported in the section directly above. Thus, these results are not duplicated here.

Perceived Sleep Quality. The couple level ICC was 0.13, indicating that 13% of the variance in sleep efficiency can be attributed to the couple level. The initial three-level model (using equations described above) indicated that scent type was not a significant predictor of sleep efficiency (*b* = 0.15, *SE* = 0.08, *p* = .074, *95% CI* [-0.02; 0.31]). As with sleep efficiency, when rounded to the second decimal place, results of the model predicting perceived sleep quality from scent type are identical to results from the two-level model. Thus, these results are not duplicated here.

B.9 Results Removing Sample 1 Data

When only data from sample 2 & 3 are analyzed (sample 1 data is removed), mean sleep efficiency is descriptively higher on nights spent with a partner's shirt than a control shirt (86.91% and 85.56%, respectively, *d* = 0.16). However, the initial multilevel model (predicting sleep efficiency from scent type) indicates that scent type is not a significant predictor of sleep efficiency (*b* = 1.24, *SE* = 0.76, *p* = .052, *95% CI* [-0.16; 2.73][16]), though the direction of the result is consistent with the complete dataset.

B.10 Sleep Efficiency Components

We did not have a priori hypotheses about how individual components of sleep efficiency (Onset Latency, Wake After Sleep Onset) would relate to scent. On an exploratory basis, we examined each component separately.

Onset Latency. Onset latency is the amount of time taken to fall asleep for the first time on a given night. Results indicate that onset latency was lower on nights spent with a partner's shirt than a control shirt (10.60 and 18.69 respectively; *t*(154) = 4.14, *p* < .001, mean difference

16 Unlike sample 1, we preregistered the use of a one-tailed t-test for sample 2 and sample 3. Therefore, we report results using a one-tailed test.

= 8.09, *95% CI* [4.23; 11.96]). The initial MLM (using equations identical to those used for sleep efficiency in the main manuscript) also indicated that scent type was a significant predictor of onset latency (b = -8.11, SE = 2.18, p < .001, *95% CI* [-12.35; -3.48]).

Upon visual inspection, it was apparent that three values for onset latency were extreme outliers (179, 198 & 215 minutes; these numbers were over 6 SDs above the mean). Removal of these three data points did not change the direction or inferential implications of the results (b = -6.37, SE = 1.97, p = .001, *95% CI* [-10.34; -2.13]).

Wake After Sleep Onset (WASO). WASO, is the amount of time an individual is awake during the night after they have initially fallen asleep. Results indicate that WASO was lower on nights spent with a partner's shirt than a control shirt (31.33 and 33.80 respectively; $t(154)$ = 1.41, p = .16, mean difference = 2.47, *95% CI* [-0.99; 5.94]). The initial multilevel model (using equations identical to those used above) indicated that results are in the same direction as onset latency but are not statistically significant (b = -2.68, SE = 2.14, p = 0.21, *95% CI* [-6.61; 1.54]).

Upon visual inspection, it was apparent that one value for WASO was an extreme outlier (307 minutes – the next highest number was 172.5; this value was over 6 SDs from the mean). Removal of this one night did not change the direction of results, but it did cause scent type to become a significant predictor of WASO (b = -3.66, SE = 1.64, p = .026, *95% CI* [-6.72; -0.31]).

B.11 Distribution of Relationship Quality & Attachment Style Data

The three boxplots below show the distribution of scores for the relationship quality and attachment variables (all three were measured on 7-point Likert scales). It is apparent that the participants in this dataset rate their relationship quality highly. They are also, for the most part, below the midpoint of the scale on both avoidant and ambivalent attachment, indicating that they are relatively secure in their romantic relationships. Thus, the current dataset has range restriction when examining interactions with these variables and scent (for example, since no participants report being unhappy in their relationships, it is not possible with these data to examine if people who are unhappy in their relationship respond to their partner's scent differently).

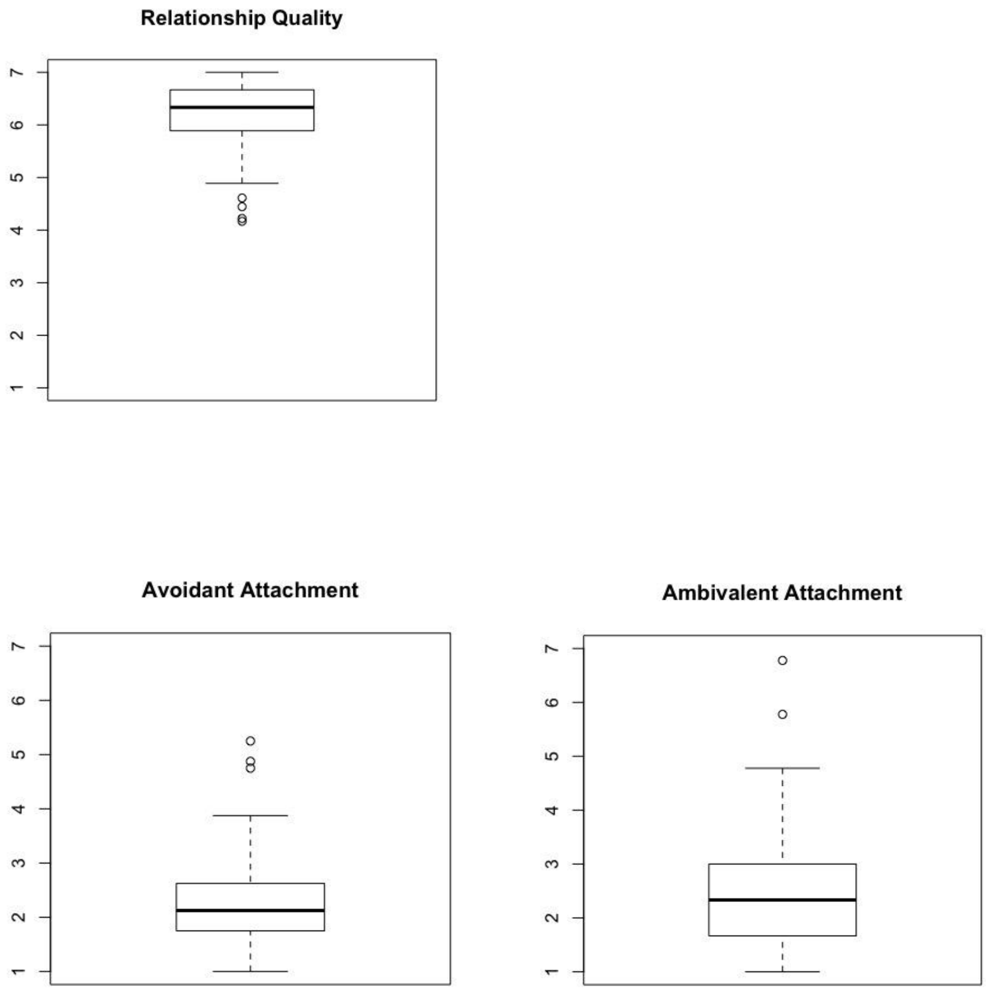

Figure B.3. **Relationship characteristics reported by participants on a scale of 1 (low) to 7 (high).**

B.12 Belief Accuracy about Scent Exposure

We also examined the accuracy of people's beliefs about what they were smelling. Outside of a lab experiment, participants are likely to have knowledge about the origin of the scents they encounter (e.g. partner scents are encountered when sleeping on a partner's side of the bed; stranger scents are encountered in novel settings). Thus, data from nights when participants accurately identified the scent to which they were exposed arguably have the most external validity. Table B.30 shows that on 436 of the 619 total nights, participants identified the scent accurately[17]. Results shown below are on this subset of 436 nights.

Table B.30. ***Accuracy in participants' beliefs about scent exposure***

	Accuracy		
Scent Exposure	Accurate	Inaccurate	Total (n)
Partner Scent	204	105	309
Control Scent	232	78	310
Total (n)	436	183	619

Belief Accuracy

Sleep Efficiency. For the 436 nights when participants accurately identified the scent to which they were exposed, an MLM model was computed predicting sleep efficiency from scent, employing the following equations:

[17] At the end of the experiment, participants were asked about their beliefs. In Study 1, participants were asked "Do you think this item belongs to your partner?" in regard to both shirts. In Study 2, participants were asked "Do you think one of the shirts was worn by your partner?" and "If you had to choose, which shirt do you think was worn by your partner?" In Study 3, participants were asked "Do you think this shirt was worn by: your partner, another person, unworn, other" in regard to both shirts. On nights spent with a partner's shirt, if participants accurately identified the shirt belonging to their partner, they were coded 1; otherwise 0. On nights spent with the control shirt, if participants accurately identified the shirt as not belonging to their partner they were coded as 1, otherwise 0.

Level 1: $\text{Sleep}_{ij} = b_{0j} + b_{1j}(\text{Scent}_{ij}) + e_{ij}$

Level 2: $b_{0j} = \gamma_{00} + u_{0j}$

$b_{1j} = \gamma_{10} + u_{1j}$

Results indicated that scent significantly predicted sleep efficiency (b = 2.89, SE = 1.00, p = .004, *95% CI* [0.79; 4.92]). The magnitude of this relationship was similar to that of the whole sample (the coefficient for the whole sample was b = 2.58).

Perceived Sleep Quality. A second analysis was computed predicting perceived sleep quality using the MLM model described above. Results indicated that a partner's scent predicted higher sleep quality than a control scent in participants who had an accurate belief of the scent to which they were exposed (b = 0.29, SE = 0.09, p = .002, *95% CI* [0.11; 0.48]). This relationship was not significant in the entire sample (though it was trending in this direction).