WHAT UNDERLIES SECURITY? NEUROLOGICAL EVIDENCE FOR ATTACHMENT'S RESOURCE ENHANCEMENT ROLE

BY

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Abstract

The sense of attachment security has been linked with a host of beneficial outcomes related to personal and relational well-being. Moreover, experimental research has demonstrated that the sense of attachment security can be enhanced via cognitive priming techniques, and studies using these methods have shown that security priming can affect behavioral responses in ways similar to dispositional attachment security. The underlying neurological mechanisms by which security priming operate have been yet unknown, however. The current paper proposes three main components of security priming which include affect, cognition, and behavior. An fMRI study involving supraliminal and subliminal experimental priming then tests the conceptualization by exploring the underlying neural mechanisms of security. Results show patterns of brain activation reflective of affective (e.g., feelings of reward in the putamen), cognitive (e.g., regulatory processes in the medial frontal cortex), and behavioral (e.g., goal direction in BA 6) processes. Differences in activation as a result of individual differences in attachment are found in response to security priming reflecting individual differences in the process of security attainment. For instance, people high in anxiety had increased activation in attention, emotion, and regulatory areas in response to the subliminal prime, indicative of their hypervigilance to attachment-related stimuli and hyperactivating strategies. Overall, the brain activation parallels the proposed mechanisms of the sense of security, setting it apart from other constructs such as romantic love and demonstrating its role as a unique mental resource.

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Table of Contents

List of Tables

List of Figures

What underlies security? Neurological evidence for attachment's resource enhancement role

Attachment security is the sense that the world is generally safe, close others will be there when needed, and one can explore the environment curiously and confidently and engage rewardingly with other people (Mikulincer & Shaver, 2007a). Feeling secure—or having a sense of attachment security—is known to be associated with numerous positive outcomes, including personal factors such as self-esteem and emotion regulation, and relational factors such as greater relationship satisfaction and stability. Security, from an attachment perspective (Bowlby, 1969/1982), is thought to be largely dispositional in nature (people possess an *attachment style*), involving expectations about the self and others which influence relationship-related affect, cognition, and behavior. However, there is an increasing amount of evidence that attachment security can be situationally enhanced by cognitive methods, such as exposure to attachment security-related words (i.e., priming). Moreover, like attachment security, security enhancement has been found to have beneficial effects, such as increasing ethnic tolerance, cognitive openness, emotional stability, and well-being both in the short and the long term (e.g., Gillath, Selcuk, & Shaver, 2008; Mikulincer & Shaver, 2001; Mikulincer, Shaver, & Horesh, 2006).

Although a few theoretical explanations have been suggested to account for the effects of security priming (e.g., increased mental resources, enhanced positive affect, a calming sensation; see Canterberry & Gillath, in preparation; Mikulincer & Shaver, 2007b), the exact mechanisms underlying attachment security and its enhancement are still poorly understood. The current investigation therefore used a social-cognitive-neuroscientific approach to further the understanding of these mechanisms. Specifically, functional magnetic resonance imaging (fMRI) was used to identify potential mechanisms related to security enhancement by focusing on brain regions that become active when people are exposed to security primes. Below I provide an overview of security within an attachment framework, followed by evidence of the affective, cognitive, and behavioral outcomes of security enhancement, and a review of the potential neurological processes associated with these outcomes.

Origins of Security According to the Attachment Theoretical Framework

Attachment security is situated within a social context. Through the process of evolution, humans have developed as social creatures. Because in the environment of evolutionary adaptedness (Bowlby, 1969/1982) being affiliated with other people presumably promoted survival, the desire to have relationships with other people and feel accepted by them have evolved and remained a crucial part of human nature to-date (e.g., Baumeister & Leary, 1995). Being associated with others or being in a relationship provides a number of benefits. When our ancestors roamed the savannah, close others provided protection, resources, and ways to increase the likelihood of passing forward one's genes. Being socially excluded, therefore, increased the likelihood of death due to lack of access to resources or protection, and decreased the likelihood of passing forward one's genes (i.e., access to mates). According to inclusive fitness theory (Hamilton, 1964) because we share genetic material with family and potentially other group members (clan, tribe, etc.) the survival of our family and group members would be beneficial for the individual—serving the ultimate goal of survival (Dawkins, 1976). Security in this context serves as a sign of not only being free of direct physical danger, but also freedom from social danger, such as exclusion, and its potential outcomes. The importance of social relationships for human survival is thought to account for the development of a behavioral system designed with a goal of maintaining or regaining safety and security in social relationships.

Attachment theory provides one of the most heavily researched frameworks for understanding the development and functions of security in close relationships with thousands of theoretical and research articles that have been published since its creation (e.g., Ainsworth, Blehar, Waters, & Wall, 1978; Bowlby, 1969/1982; Mikulincer & Shaver, 2007a). Bowlby's theory of human attachment is based on ethological studies of nonhuman animals and rooted in cognitive and evolutionary theories. The theory provides an account for close relationship formation or attachment bonding, with the default result of this bonding being the experience of security. Attachment theory stipulates that because human babies are virtually helpless in infancy, requiring extensive care and support, maintaining proximity to a caregiver is important for survival. Thus, through the process of evolution, humans have developed a tendency to promote proximity to others who can provide protection and support. However, in addition to having a survival function, proximity maintenance has moved beyond survival and shaped our tendency and ability to form social bonds in general.

The relationship between an infant and the primary caregiver has been termed an *attachment relationship*, the caregiver termed an *attachment figure*, and the state resulting from having one's safety needs met has been termed *security*. When in a situation posing potential threat or when unable to care for oneself, the *attachment system* is activated and it motivates people to seek proximity to a stronger wiser other—an attachment figure. The proximity-seeking strategy and the attachment-related behaviors (e.g., crying, smiling, reaching), which promote attainment of proximity are thought to have increased the likelihood of survival—by keeping the child close to someone who could provide his or her needs—in ancestral environments. Once the needs are fulfilled, a sense of security signifies to the child that things are back to normal and other activities (rather than pursuing one's caregiver) can take place.

Attachment literature suggests that in the long run provision of comfort and relief by one's attachment figures contributes to the development of a dispositional sense of attachment security (e.g., Bowlby, 1969/1982). Bowlby suggested that over repeated experiences people develop mental models, termed *internal working models* (IWMs), that affect how they perceive themselves (as worthy of being loved), others (can be relied upon to keep one safe from threats or dangers) and the world (as predictable and safe). As a result of feeling secure, one is less likely to be anxious about his or her ability to cope with threats, whether with the help of an attachment figure or independently. Feeling safe and secure also facilitates other capabilities and behaviors, such as exploration (feeling safe enough to leave the side of the caregiver and investigate something new), caregiving (having one's own security needs met allows one to then provide help to others in need), and affiliation (knowing that one's primary caregiver can be trusted promotes a confidence in the self and a positive approach to others—that they can be trusted as well).

However, while a dispositional sense of security is likely to develop from successful attempts at security attainment, some attachment figures do not consistently fulfill a person's attachment needs. Repeated unsuccessful attempts at attaining security are likely to result in a sense of attachment insecurity. In this case, the default IWM may reflect perceptions of the self as unworthy of receiving care and of others as unable to be relied upon.

Adult Attachment

Originally attachment theory was concerned with the relationship between an infant and his or her primary caregiver; however, Hazan and Shaver (1987) applied Bowlby's theoretical framework and Ainsworth and colleagues' (1978) categorization system of infant attachment to the domain of romantic relationships (see also George, Kaplan & Main, 1985). Thus, an individual's approach to adult romantic relationships can be characterized by attachment styles, commonly operationalized as either *secure* or *insecure*, with insecure attachment styles further parsed into *attachment anxiety* and *attachment avoidance* (e.g., Brennan, Clark, Shaver, 1998; Fraley & Waller, 1998).

Attachment anxiety is thought to result from having a caregiver who is inconsistent and intrusive in his or her parenting (for a review, see Mikulincer & Shaver 2007a). As an adult, levels of attachment anxiety reflect the degree to which a person worries about potential rejection or a partner's lack of availability in times of need. Attachment anxiety is also thought to reflect the tendency to be clingy and hypervigilant to attachment-related threats, and often results in the adoption of a secondary strategy of dealing with security concerns—a hyperactivating strategy. The hyperactivating strategy results with the attachment system being chronically activated, and the person being constantly vulnerable and in need of help (Shaver & Mikulincer, 2002).

Attachment avoidance is thought to result from having a caregiver who is cold and rejecting, and encourages the child to cope on his or her own. As an adult, the level of attachment avoidance reflects a person's distrust in relationship partners' availability and the tendency to maintain behavioral independence and emotional distance from relationship partners. People high on attachment avoidance tend to adopt a deactivating secondary strategy, which involves an increased threshold for threat (e.g., any perceived threat that may lead to security-seeking) and attempts to downplay the need for closeness or help—which Bowlby referred to as compulsive self-reliance (Shaver & Mikulincer, 2002).

Mikulincer and Shaver (2003) presented a model depicting the dynamics of the *attachment system*, and the resulting sense of security (or insecurity). According to the model, attachment is an evolved behavioral system that is inherent in humans as a result of the process of evolution. This cognitive-behavioral oriented system explains how security seeking behaviors are being activated and how the desired security can be met. As a behavioral system, attachment involves the choice, activation, and termination of sequences of behaviors that are designed to affect a functional change in the environment (Mikulincer & Shaver, 2003).

The main goal of the attachment behavioral system is the attainment of or maintenance of security in order to promote survival by assuring freedom from threat. Security, hence, can be perceived as the set-goal of the attachment system: to re-attain or maintain actual safety, which would result with a sense of security. Although the activation of the system is thought to be similar in childhood and adulthood (presence of relationship-related or -unrelated threats), regaining security in adulthood can be achieved symbolically by retrieving the internalized representation of an attachment figure and incidents when support was provided rather than through actual physical proximity (e.g., Baldwin, Keelan, Fehr, Enns, & Koh-Rangarajoo, 1996). Once the attachment system is activated (based on the perception that a threat exists and is relevant for oneself), a series of decisions are being made (either consciously or unconsciously; Mikulincer et al., 2002). The person has to decide if an attachment figure is available and responsive. If the answers to these questions are yes, then the set-goal—security—is met.

According to the attachment framework, while the particular relationship partner (or attachment figure) and threat-related situation are not discounted, being high in attachment security is akin to a personality trait. It is presumed to be constant from relationship to relationship and transferred from existing relationships to future ones (e.g., Brumbaugh & Fraley, 2006), such that people high in attachment security have cognitive structures or mechanisms that foster the maintenance of security in the long term. Nevertheless, it is known that people can have different general feelings of security or insecurity in different relationships and that even people who have a chronic dispositional insecurity can still feel secure in certain contexts, and especially when security is experimentally primed (e.g., Gillath & Shaver, 2007). Thus, security priming, which is presumed to activate secure IWMs, can induce people to behave more in line with a secure attachment style. How exactly security priming works—via which mechanisms—can help in understanding how security comes to impart its benefits more generally.

Using Security Priming to Understand the Underlying Mechanisms of Security

Priming methods involve presenting people with a particular stimulus type prior to completion of a task. The cue or stimulus is thought to activate specific cognitive networks, induce affective states, and hence affect subsequent responses (e.g., Baldwin, 1997). Researchers have used various priming techniques in an attempt to activate a security-related mental network. Much of the security priming work attempts to activate or increase one's feelings of comfort, safety, and support. In most of these studies, security primes, as compared with control primes (e.g., neutral or affective), resulted with cognitive, affective, and behavioral responses thought to be associated with the activation of other behavioral systems (e.g., exploration, affiliation, caregiving) when people feel secure (see reviews Gillath et al., 2008; Mikulincer & Shaver, 2007b). As suggested by Baldwin and others, security priming is effective even for people who are chronically insecure, potentially through their ability to activate secure IWMs (e.g., Gillath & Shaver, 2007; Mikulincer & Shaver, 2007b). This suggests that priming security puts people in a state that provides them resources or strategies that generally characterize people who feel accepted and supported by close relationship partners (e.g., Higgins, 2000).

Recently, Mikulincer and Shaver (2007b) provided a review of studies involving the priming of attachment security. The sense of attachment security can be primed using various subliminal (unconscious) or supraliminal (conscious) methods. In the studies conducted to-date, both subliminal and supraliminal priming methods have proven to be successful, but the effects are sometimes inconsistent and whether the underlying process is the same is unknown (e.g., Mikulincer, Hirschberger, Nachimas, & Gillath, 2001). Some successful methods to enhance security include the supra- or sub-liminal presentation of pictures implying attachment-figure availability (e.g., a Picasso drawing of a mother cradling an infant in her arms; a couple holding hands and gazing into each other's eyes); the presentation of the names of people who serve as security-providing attachment figures, or of words associated with these people and the sense of security (e.g., love, hug, affectionate); and guided imagery concerning either the availability and supportiveness of attachment figures or security enhancing interactions (Mikulincer & Shaver, 2007b). It is expected that these research techniques seem to temporarily activate mental representations of attachment figures and the support and comfort associated with them (e.g., secure IWMs).

Clearly, other cues, unrelated to attachment, can also provide a sense of reward or calmness. However, in studies where security primes were compared with emotionally positive but attachment-unrelated stimuli (e.g., pictures of a large amount of money, or of a cute puppy, the names or faces of highly familiar acquaintances or close others who are not attachment figures) or emotionally neutral stimuli (e.g., pictures of furniture, neutral words) it was consistently found that portrayals of attachment-figure availability had beneficial effects such as improved mood, and generally did so more reliably and powerfully than other positive stimuli (Mikulincer & Shaver, 2007b).

In addition, as mentioned earlier, the security priming techniques are usually effective even for people who are relatively insecure dispositionally. Thus, many studies have demonstrated security priming effects while controlling for attachment insecurity, and found a lack of interaction between attachment insecurity and the prime (e.g., Mikulincer, et al., 2001; Mikulincer, Shaver, Gillath, & Nitzburg, 2005). However, some studies have shown an interaction between attachment insecurity and the security prime, such that people's level of attachment insecurity affects their response to the security prime (see Gillath et al., 2006, Study 2; Mikulincer, Shaver, & Rom, 2011, Study 2). For instance, Gillath and colleagues (2006) found in one study that only people low on avoidance reported an increased tendency to seek instrumental support. Thus, highly avoidant people's responses were not affected by subliminal presentation of an attachment figure's name in this study. While the security prime is expected to increase responses to be in line with a secure mental model, it is unknown if the process is the same for people that have different dispositional attachment styles. fMRI has the unique ability to explore the neurological processes that may underlie the process of security priming based on attachment style. Thus, the current investigation will explore differences in underlying mechanisms as an effect of attachment style.

Processes Leading to Security Attainment

According to Mikulincer and Shaver (2007b) and Gillath et al. (2008) who reviewed the effects of security priming, security priming leads to changes in domains such as: mental health, perceptions of self and others, altruism, and intergroup processes. Canterberry & Gillath (in preparation) further suggested that security priming and the effects of security involve three main components: affect, cognition, and behavior. In the affective domain, security is associated with attenuation of negative affect, increase in positive affect, and relaxation. In the cognitive domain, security is associated with spreading activation of attachment-related memories, self and other representations, and regulatory strategies. Finally, in the behavioral domain, security is associated with motivation, behavioral tendencies, and actual behaviors such as support receipt or provision. Although previous studies were focused on the effects following exposure to security primes, they did not explain the mechanisms that allow these effects to take place. The current research will use fMRI to investigate the role of these three components in security priming. Below I review empirical evidence to support the theoretical approach that security involves three main components and later connect these components with potential neural processes to better understand the mechanisms underlying security.

The Affective Component of Security

The affective component of security includes attenuation of negative affect, an increase in positive affect, and feelings of calmness and safety. Thus, security seems to play an emotion-related role resulting with relaxation and overall positive mood. Mikulincer and colleagues were among the first to provide evidence for the idea that enhanced security increases positive affect (Mikulincer et al., 2001). They collected information about participants' close others, then subliminally presented people with the names of their attachment figures during an experiment in which they were asked to rate their liking of neutral images. The priming of attachment figures, or activation of the sense of security, resulted in higher liking of neutral stimuli. This affective priming procedure suggests that security cues carry positive affect that can be transferred to previously neutral cues.

Mikulincer and colleagues (2001) also found that security increased positive affect in the presence of threatening contexts (e.g., subliminal presentation of the word "death" or "failure" preceding the security prime). The security prime eliminated the detrimental effects that threats otherwise had, an ability that other positive, but non-attachment-related cues did not have. These findings regarding the threat context suggest that security cues provide benefits through a mechanism above and beyond mere positive affect. Knowing that security cues, like positive cues, result in an increase in positive affect does not, however, tell us if security involves the same mechanisms that positive emotions involve (for example, do security and love share the same brain activation patterns). Moreover, the fact that only security cues withheld the effects of death exposure, suggests that security cues differ from positive cues, Behavioral studies, however, do not reveal what processes this difference might involve.

In a more recent study, Carnelley and Rowe (2010) showed that participants who were exposed to a security prime used more positive emotion and nostalgia words in their writing. The increase in use of nostalgia words suggests that the sense of security also provides access to (positive) memories. Nostalgia, in a separate line of research has been shown to involve thoughts about relationships and positive affect (potentially increasing the cognitive accessibility of the people we feel most secure with; Wildschut, Sedikides, Routledge, Arndt, & Cordaro, 2010). Thus, again, security seems to increase positive affect.

Security has also been shown to decrease negative affect. Mikulincer and colleagues (2006) examined whether security can mitigate post-traumatic stress disorder (PTSD) symptoms, such as affective hyperarousal. Replicating previous studies, participants with high PTSD symptomatology produced longer color-naming latencies for terror-related words on a Stroop task (indicating attentional bias toward these words) than participants in the low PTSD symptomatology group. However, this effect was not significant following the priming of security. Thus enhancing security during the Stroop task had a presumably soothing or calming effect, decreasing the heightened negative emotional response, lowering the accessibility of trauma-related thoughts and eliminating differences between PTSD and non-PTSD groups in color-naming latencies for terror-related words.

In a recent study participants were subliminally primed with attachment security-related words and then asked to imagine how they would respond to a hurtful event—one in which they were hurt by a romantic partner (Cassidy, Shaver, Mikulincer, & Lavy, 2009). Their results showed that the security prime increased the outcomes of people high in avoidance and anxiety to be more in line with behavioral tendencies associated with security. For people high in anxiety, the attachment prime reduced their intense emotional reaction to the hurtful event, including less crying and feelings of rejection. Thus, the security prime decreased negative affect. For people high in avoidance (who tend to deactivate and inhibit attachment-related feelings), following the security prime they showed more openness to experiencing the negative feelings associated with the hurtful event, such as showing less defensive hostility, and greater feelings of rejection. Thus, in this case security opened up people to experience their emotions more fully, decreasing the deactivating strategies of avoidance people.

Together these studies suggest that security priming leads people to have more secure affective responses. Thus, security enhancement can improve mood, via increases in positive affect, as well as decreases in negative affect. In addition, it can reduce the use of secondary strategies (i.e., hyperactivation or deactivation) in response to threatening stimuli. In all, these findings provide evidence that security priming may allow people to be more open to the interpretation and experience of affective stimuli.

The Cognitive Component of Security

Using the concept of working models, attachment theory builds on cognitive psychology to explain security and its enhancement. Over time people internalize their interactions with their attachment figures into IWMs (Bowlby, 1969/1982). An IWM can be compared to a schema, such that a person comes to form expectations about support provision, acceptance, and nurturance from relationship partners, which guide the processing of relationship-related information (e.g., Baldwin, 1992). Working models are thought to be composed of if/then propositions, such that *if* a distressing event occurs, *then* a person should seek an attachment figure, or what may be called a safe haven. If the safe haven is available, then a sense of security is gained, but if not, another strategy (i.e., a secondary strategy) is employed. Working models, include memories of attachment-related experiences; beliefs, attitudes, and expectations about the self and others; attachment goals and needs; and plans and behavioral strategies to achieve attachment goals. As compared to the cognitive structures usually studied in social cognition research (e.g., schema or script), IWMs involve a person's wishes, fears, conflicts, and psychological defenses and are affected by these psychodynamic processes.

In an effort to attain security a person retrieves his/her IWM of secure relationships. Memories of past security seeking scenarios, beliefs about one's ability to attain security and others' ability to serve as security providing figures, and knowledge of the steps or strategies to take in order to seek and attain a sense of security can all help obtain security. Thus, when a threat is perceived, a person's expectation of the partner's willingness and ability to provide assistance or comfort may determine the person's attempt and success in gaining security (Collins & Reed, 1994). Gaining a sense of security may, in turn, free up resources to further cope with the situation (see also the broaden and build hypothesis, Fredrickson, 1998). Appraising something as a threat involves negative states such as anxiety, fear, and stress, all of which tax one's mental resources. Security is thought to either free up mental resources, which otherwise are tied up in the response to the threat, or add additional mental resources. In both cases, the additional mental resources improve people's ability to regulate emotions and cope with stress. In turn, this improved ability allows people to respond to events with a range of reactions, thus coping with rather than avoiding the events.

In addition to promoting the use of secure working models, security priming seems to lead to an increase in people's ability to mentalize, which involves an understanding of one's own and other people's behaviors as related to mental states, including feelings, beliefs, and needs (Fonagy, Gergely, Jurist, & Target, 2002). Concepts related to mentalizing, such as showing empathy and being able to see things from another person's point of view, have been linked with attachment security as demonstrated below. Thus, this security prime or the secure working model may provide people with cognitive resources to be used in the interpretation of social and other-related information and facilitate prosocial responses.

The secure IWM, thus, involves guidelines on how to cope, expectations about potential help and about the coping strategy that might work, and resources to carry out the chosen strategy. Together these cognitions seem to positively affect people's self-perception and improve their coping. For example, Baccus, Baldwin, and Packer (2004) showed that priming people with security cues (stimuli indicative of love and acceptance) increased participants' self-esteem. Likewise, studies priming a sense of security by asking participants to think about someone that accepts them have demonstrated that feeling loved and accepted can limit one's need to use defensive strategies in an attempt to maintain positive feelings of the self (Arndt, Schimel, Greenberg, & Pyszczynski, 2002; Schimel, Arndt, Pyszczynski, & Greenberg, 2001). For instance, Schmiel and colleagues (2001) presented participants with false feedback about performance on a task and gave them the opportunity to view the responses of other people in order to compare themselves with people who had done more poorly. When people had been instructed to think about an accepting other beforehand, they chose to look at fewer responses of others, indicating a lower need to make downward social comparisons. Presumably the thoughts of a loving, accepting other increased people's security, which in turn increased positive cognitions about the self, and reduced the need to make self-enhancing social comparisons, thus reducing defenses.

In addition to increasing positive cognitions and decreasing defensive strategies regarding the self, a sense of security has been shown to increase positive expectations about one's relationship (Carnelley & Rowe, 2007; Rowe & Carnelley, 2003). In particular, Rowe and Carnelley's research demonstrates that a sense of security seems to alter a person's expectations regarding relationship partners in line with a secure working model. When people were primed with security over five time points (via presentation of an attachment figure's name and writing about a secure experience), they showed an increase in both positive self-views (self-liking and self-confidence) and relationship expectations.

These studies highlight aspects of the sense of security that are associated with the processing of self, partner, and relationship-related information. Thus, security seems to provide more than just affective components, altering the way information is processed. Specifically, information processing involves more positive perceptions of the self and partner and promotes the relationship. Evidence from the studies reviewed indicates that security may decrease defenses, and provide new strategies affecting expectations. Security may allow for better thought- or self-control, allowing people to select which schemas to use, and which strategies to rely on. Security, in this regard, therefore appears to act like a mental resource that improves information processing.

The Behavioral Component of Security

The behavioral component of security includes motivation, behavioral tendencies, and actual behaviors. Most previous studies have demonstrated that when people feel secure other behavioral systems become active—people help others, explore their environment, et cetera. For example, Mikulincer and colleagues (2005) examined the effects of security on willingness to help a person in need. In one study, participants came into the laboratory and viewed another participant (who was actually a confederate) undergoing aversive tasks (such as petting a tarantula). At one point the confederate became upset as a result of the aversive tasks and stated that she would be unable to complete the study. At this point the participant was given the option to help out by taking her place and completing the remaining tasks. Prior to the task, some participants had received experimental enhancement of security. Whereas among people not receiving the security enhancement (subliminal presentation of the name of their attachment figure) only about 30% of participants were willing to help out by completing the remaining tasks among those who were primed with security, close to 70% agreed to take the confederate's place. This indicates that thoughts of security can affect behavioral responses of caregiving.

In another study, Gillath and Shaver (2007) demonstrated that security priming affects behavioral tendencies—making people report a tendency to behave more in line with their secure working models. Thus, Gillath and Shaver (2007) presented participants with different relationship scenarios and measured how likely they were to choose a secure behavioral response. Increasing participants' sense of security (as opposed to insecurity) by asking them to think about a sensitive, supportive relationship prior to completing the questionnaire resulted in the tendency to choose more secure behavioral strategies, such as opening up to a partner or providing support to a partner.

Priming people with attachment has also increased their openness to new experiences or exploration. For example, Green and Campbell (2000) primed security by presenting participants with security-related sentences. Participants primed with security showed more interest in engaging in social activities, such as taking part in a group task and participating in a “mystery experiment”. Thus, by achieving a sense of security, participants were presumably able to devote more resources to other behavioral systems, like exploration. Similarly, a set of studies involving both subliminal and supraliminal security priming showed that security priming increases creativity, as measured by responses in a word-game task (Mikulincer et al., 2011),

Finally, in a recent series of studies, Gillath and colleagues (Gillath, Sesko, Shaver, & Chun, 2010) showed that enhancing attachment security affected people’s behavior such that they were more likely to report both positive and negative qualities and experiences, as compared to people not primed with security (be more authentic). They also found that security resulted in a decreased tendency to lie on an IQ test.

Research investigating the behavioral components reveals that security results in the use of behavioral strategies promoting social relationships. Security seems to facilitate behaviors including altruism, constructive responses to relationship threats, openness to experience, and being more creative, authentic, and honest. These studies show that when people feel secure, their behaviors are directed in a way that promotes the self and relationships. Thus, the sense of security not only increases positive affect and promotes the use of secure working models, but it also motivates behavior.

As demonstrated in the previous section, studies involving security priming have demonstrated effects in a variety of areas indicating that enhanced security involves affective, cognitive, and behavioral components. However, the reviewed studies above did not reveal the underlying mechanisms of these components. For instance, I propose that security priming involves affective, cognitive, and behavioral components, but behavioral studies tend to elucidate one or two components at a time. Neuroimaging allows for the ability to determine if all three components are simultaneously involved in security enhancement. In the next section I use neuroscientific literature to review potential neural mechanisms underlying attachment security.

Potential Underlying Neural Mechanisms of Security

Potential Mechanisms Underlying the Affective Component

Animal research provides insight into the role of neurological mechanisms in bonding behaviors, which are thought to serve as the basis for the attachment behaviors and security seen in humans. Over the past decade research on voles, a species of rodent, has provided a means to understand the formation of pair bonds and, more specifically, the role of oxytocin in social behavior (e.g., Carter, DeVries, & Getz, 1995; Insel & Young, 2001). Oxytocin is a neuropeptide and a hormone that is produced and released in the brain. It has been shown to be involved in mating and parenting behaviors, and in the stress response (see Carter, 1998; Diamond, 2001). Prairie voles form monogamous sexual relationships, as opposed to other types of voles including montane voles, which do not develop these monogamous relationships. Thus, prairie voles provide an opportunity to learn more about the neurological processes involved in the formation of what researchers have termed *attachment bonds*.

It has been discovered that the monogamous prairie voles uniquely possess receptors for oxytocin in reward-related areas of the brain. These receptors may lead bonding to be perceived as a positive experience. For example, monogamous prairie voles have oxytocin receptors in the nucleus accumbens and the ventral pallidum; whereas nonmanogamous voles do not (e.g., Insel, 2010; Insel & Shapiro, 1992). Monogamous prairie voles also demonstrate an increased stress response to social isolation (Shapiro & Insel, 1990), suggesting that these brain mechanisms may be associated with attachment process and the desire for belongingness and security in humans. The study of the security-related brain mechanisms among humans cannot use the same methods as those used with animals (for ethical reasons), and hence is mainly based on noninvasive neuroimaging.

While there has not been an investigation of the brain activation underlying attachment security in humans per se, some studies with humans provide insight into potential neural mechanisms of security. For example, some of the underlying mechanisms of love are expected to be associated with security (indeed, the word “love” is often one of a set of words used to prime security), such that a positive affective experience underlies both. In a study investigating love, when exposing people to the face of the person participants reported being in love with while undergoing fMRI, Aron and colleagues (2005) found activation in reward systems, related to dopamine production. Specifically they found that in comparison to viewing pictures of an acquaintance, viewing their loved ones resulted with activation in the ventral tegmental area (VTA) and caudate (both related to reward). Aron et al. (2005; see also Fisher, Aron, & Brown, 2005) suggested this activation to be related to a dopaminergic reward pathway. Thus, the experience of love involves a positive emotional experience.

In a previous set of studies, Bartels and Zeki (2000; 2004) suggested that the activation in response to pictures of loved ones in regions associated with reward and emotion (e.g., caudate and VTA), is affected by having a high density of oxytocin and dopamine receptors in those areas. This suggests that the affective component of security in humans may be linked with oxytocin in the brain. Bartels and Zeki (2004) additionally found overlapping areas of activation in response to romantic and maternal love objects in the striatum (e.g., putamen, globus pallidus, caudate), the insula, and the dorsal part of the anterior cingulate cortex (ACC). These studies suggest that parental attachment, and romantic attachment might be based on similar underlying mechanisms—mechanisms that underlie the sense of security.

Potential Mechanisms Underlying the Cognitive Component

In a more recent investigation of love, Ortigue and colleagues (Ortigue, Bianchi-Demicheli, Hamilton, & Grafton, 2007) subliminally presented people with a beloved one's name (as opposed to either a friend's name or a word indicating the participant's passionate hobby) to provide further understanding of the implicit response to love. In response to the loved one versus a friend name, they found activation, similar to previous studies, in areas including the caudate, VTA, and insula (related to affective responses mentioned earlier). Similar areas were activated when comparing the passion prime with the friend prime, indicating that those areas may be related to emotion and motivation more generally. However, when comparing the romantic partner's name to a passionate hobby, the loved one was uniquely associated with bilateral angular gyri and bilateral fusiform regions. Ortigue and colleagues note that these areas are associated with memory retrieval and abstract representations of others. The approach of Ortigue and colleages may indicate areas unique to romantic love (or attachment relationships), versus those associated with love more generally (e.g., love for a hobby). Moreover, the links with memory and representation of others could be indicative of participants assessing secure working models which involve memories of past secure scenarios and attachment figures, as well as expectations of the partner.

Based on experimental studies, however, while there may be some overlap security priming is expected to activate areas beyond those activated by love. Because security has been shown to increase things like positive perceptions of the self and the use of more secure relationship strategies, security is expected to be associated with areas of the brain linked with cognitive resources, regulation, and processing of social information. For instance, the process of security attainment is inherently social (attachment evolved to promote survival by assuring proximity to stronger wiser other). Thus, security priming is also expected to be involved with brain activation related to the processing of social information. The processing of social stimuli has been found to be associated with activation in certain areas of the brain. When Britton and colleagues (2006) exposed participants to social emotional stimuli (joy and sadness) as compared to nonsocial emotional stimuli (appetite and disgust), they found activation in the superior temporal gyrus, posterior cingulate, hippocampus, and amygdala. Moreover, in numerous studies, superior temporal regions have been associated with social perception and are thought to be integral to social information processing (e.g., Allison, Puce & McCarthy, 2000; Hoekert, Bais, Kahn, & Aleman, 2008; Narumato, Okadab, Sadatob, Fukuia, & Yonekura, 2001). The areas important in social information processing more generally, may also be linked with activation of secure working models and the outcomes related to perception of self and others that can result.

In addition, as behavioral studies have shown that security priming alters our expectations of others and increases prosocial behaviors, cognitive processes associated with empathy and perception of others, or mentalization, may underlie security processes. A study by Lawrence and colleagues (2006) explored these kinds of responses using fMRI. In a study in which people indicated the emotional states of others, areas of activation associated with social perceptual processes included the middle frontal gyrus (BA 46), the superior frontal gyrus (BA 6/8), the fusiform gyrus, and the middle temporal gyrus. In addition, areas correlated with increases in empathy scores included the putamen, middle temporal gyrus (BA 21), inferior frontal gyrus (BA 45), precentral gyrus (BA 4), medial frontal gyrus, and the middle frontal gyrus. Because enhanced security tends to lead to increases in prosocial responses, the areas mentioned above may underlie the cognitive processes involved in security which lead to prosocial behavioral outcomes.

Areas of the brain that have been linked with regulatory processes more generally, may also be active in response to security priming. Because security priming can increase secure responses even in insecure people, it is expected that the security prime provides additional resources to be used in regulating cognitive and emotional responses to stimuli. For instance, the medial frontal cortex has been associated with anticipating outcomes, accessing self-knowledge (or authentic feelings like in Gillath et al., 2010), perception of others, and making inferences about others' thoughts (Amodio & Frith, 2006). In addition, the prefrontal cortex, orbitofrontal cortex (OFC), and the cingulate cortex have been shown in neuroimaging studies to be associated with regulatory, top-down processes, which can affect the interpretation of stimuli and expectations about outcomes (Ochsner & Gross, 2005). The controlled regulatory processes suggested by Ochsner and Gross are similar to those expected as a result of the activation of a secure IWM. Thus, security may allow people to implement reappraisal processes, affecting such things as the interpretation of the environment and their emotional state in a way that is more in line with a secure working model. Because security priming is presumed to increase cognitive capacities or resources, it is expected to be associated with brain activation in areas associated with general cognitive and regulatory processes. Obtaining such brain activation would provide evidence to support the conceptualization of security as a mental resource, providing people with an increased ability to process information and regulate their responses to stimuli.

Potential Mechanisms Underlying the Behavioral Component

Some of the research reviewed above points to potential mechanisms motivating behavior as well as underlying affective and cognitive responses (e.g., experiencing empathy). Animal (human and non-human) research has led to the suggestion that the neurological pathway of oxytocin, together with dopamine-related processes involved in mating behaviors and attachment relationships act as reinforcers. In this way, bonding (or security-related) experiences increase positive associations, which in humans may be experienced as positive affect. This affective experience, in turn, motivates behaviors which may encourage bonding. This suggests that the positive feelings that result from attachment relationships, and possibly security, may be facilitated by oxytocin release in the brain and may be associated with brain areas involving oxytocin receptors and behavioral motivation (Campbell, 2010; Diamond, 2002; Insel, 2010).

For instance, Carter (1998) suggests that oxytocin release may function to affect behavior in more than one way. Specifically oxytocin is thought to (1) facilitate reduction of stress response [hypothalamic-pituitary-adrenal axis (HPA) activity], (2) facilitate social attachment and bonding behaviors, and (3) be involved in the link between positive social behaviors and a decrease in fear or anxiety (Carter, 1998). These functions of oxytocin are similar to those associated with security, suggesting brain areas associated with oxytocin can be an underlying mechanism of security. Campbell (2010) suggests that oxytocin is released in response to acute threats and promotes social behavior and the motivation to seek closeness. Once closeness is achieved there is an increase in reward and positive affect. These animal models suggest that humans would have similar mechanisms involved in the sense of security, and specifically reward, and positive mood.

In the studies involving love described previously, in addition to activation in areas related to reward, there was increased activation in motivation-related areas as well. For instance both Aron and colleagues (2005) and Bartels and Zeki (2000; 2004) found activation in the ventral tegmental area (VTA) and caudate. Activation in additional areas of the striatum (e.g., putamen; Bartels & Zeki, 2000; 2004) was also found. These areas have a high concentration of oxytocin receptors in the human brain and are known to be involved with more than just positive affect, but motivated behavior as well. Thus, the experience of love involves a positive emotional experience, but may additionally serve as a motivator to bond with others.

In a recent meta-analysis of the fMRI studies that have been conducted on love, Ortigue and colleagues (Ortigue, Bianchi-Demicheli, Patel, Frum, & Lewis, 2010) concluded that the brain activation underlying love includes a subcortical reward-related system comprised of brain areas rich in dopamine and oxytocin receptors. For romantic love, in particular, the VTA (related to reward) and the caudate (related goal representation and reward detection), both resulting in pleasurable feelings, are important. In addition, some studies found activation in cortical areas (e.g., fusiform gyrus, superior temporal gyrus) indicating higher order cognitive processes related to social cognition (Ortigue et al., 2010), which potentially is indicative of the activation of the IWM. These findings suggest that love or potentially security, as a prime, involves a specific neural network rooted in the dopaminergic-motivation system, and related to reward, motivation, emotion, and mental representations of the self and others as found in previous behavioral studies. Thus, in a similar way, the positive affect and reward resulting from security priming may lead to motivated responses.

There has been some additional research that has directly investigated the neural underpinnings of attachment, although it is more focused on attachment insecurity rather than security (e.g., Buchheim et al., 2006; Buchheim et al., 2008; Gillath et al., 2005; Lemche et al., 2006). In these studies, specific brain regions, including the amygdala and anterior temporal pole (which have been associated with negative emotion), were identified as highly activated when attachment insecurity was salient (Buchheim et al., 2006; Gillath et al., 2005; Lemche et al., 2006). More recently, Warren and colleagues (2010) investigated attachment-related responses to emotional words during a Stroop task. They found that lower security (as measured by lower knowledge of the secure-base script) was associated with increased activation in areas related to attention and control (e.g., OFC, superior frontal gyrus) in response to unpleasant words. Thus, higher insecurity led to increased regulatory attempts.

The Current Study

The current study examines the neural correlates of enhancement of attachment security and how they differ from the correlates of the induction of an attachment-related state of insecurity. It also compares the neurological processes involved with different levels of awareness of the security prime (subliminal versus supraliminal). Although most studies tend to find similar effects of the exposure to supraliminal and subliminal security primes (e.g., Mikulincer, Gillath et al., 2001; Mikulincer et al., 2005), while the process is expected to be largely the same, the current study will test whether level of awareness affects the patterns of brain activation. Based on existing literature, security priming is anticipated to be associated with brain activation in regions related to heightened positive affect, enhanced emotion regulation, reward and motivation or behavior (see Table 1). Specifically it is predicted when exposed to a security prime participants will show higher activation in emotion regulation-related regions (e.g., prefrontal areas such as the orbitofrontal cortex and medial frontal cortex), reward-related regions (e.g., VTA, caudate), and the fusiform gyrus and superior frontal gyrus, which have been previously related to emotional and social processing (Britton et al., 2006; Norris & Cacioppo, 2007). Analysis will be conducted across the whole brain to determine which areas are associated with security priming, in addition to the targeting of specific a priori regions of interest (ROIs).

Method

Participants

Participants were 30 men (N = 15) and women recruited via flyers announcing a study investigating brain mechanisms and offering ten dollars per hour for participation. All participants reported having no history of psychiatric illness or neurological injury, and were right-handed, native-English speakers, and had normal or corrected-to-normal vision. Their ages ranged from 18-24 with a mean age of 21.4. All participants signed a written consent form explaining the nature of the study and potential risks involved with magnetic resonance imaging that was approved by the Institutional Review Board. All participants completed the study and were paid for their time.

Measures

State Adult Attachment Measure. To determine how a person's current state of attachment security relates to their brain activation following security primes, participants, prior to completing the functional imaging task, were asked to complete the State Adult Attachment Measure (SAAM, Gillath, Hart, Noftle, & Stockdale, 2009). The original SAAM contains 21 items measuring three factors: state attachment anxiety (e.g., "I really want to feel loved right now"), state attachment avoidance (e.g., "I'm afraid someone will want to get too close to me"), and state attachment security (e.g., "I feel like I have someone to rely on"). The anxiety- and avoidance-related items are similar to the Experiences in Close Relationships (ECR) Scale (a measure of dispositional attachment anxiety and avoidance, see below), so to limit the need for participants to respond to multiple items on the same topic, the 9-item short form of the SAAM was used. Participants were asked to indicate on a 1 (*strongly disagree*) to 7 (*strongly agree*) scale how they feel right now. State security (M = 6.07, SD = 1.02) state anxiety (M = 4.20, SD = 1.44), and state avoidance (M = 2.18, SD = 1.07) were measured with three items each and had the following reliabilities as indicated by Chronbach's alpha: α = .76, α = .75, α = .71, respectively. State security and state avoidance were negatively correlated, r = -.48, p = .008. State anxiety was not correlated with state security or avoidance.

Experiences in Close Relationships Scale. Because I was interested in the effects of individual difference in dispositional attachment style, participants also completed the ECR, a measure of attachment style (Brennan et al., 1998). The ECR contains 36 items measuring two dimensions of attachment. Eighteen items measure anxiety (e.g., "I find that my partners don't want to get as close as I would like" and "I worry about being rejected or abandoned"), and the other 18 items measure avoidance (e.g., "I find it difficult to allow myself to depend on close relationship partners" and "I prefer not to show others how I feel deep down"). Participants were asked to respond to each item by indicating how they generally feel in close relationships on a scale of 1 (*strongly disagree*) to 7 (*strongly agree*). Both subscales were reliable, Chronbach's alpha for avoidance = .95 and for anxiety = .86. Anxiety (M = 2.78, SD = .85) and avoidance (M = 2.81, SD = 1.10) scores were not significantly correlated (r = .33, p > .05).

Procedure

Upon completion of the self-report measure, participants went through an event-related computerized priming task while in the scanner. Anatomical scans were first collected, then participants completed ten practice trials to familiarize themselves with the task. The practice trials were followed by four blocks of functional scans containing 60 trials each (4 min, 30 sec per block) for a total of 240 trials. The task design was based on previous studies using priming techniques to increase levels of security (e.g., Mikulincer et al., 2001).

Participants performed a modified version of the Murphy and Zajonc's (1993) affective priming task. In the task, participants are asked to rate, as quickly as possible, how much they like various target images, using one of four buttons to indicate a liking rating between 1 (*do not like it at all*) and 4 (*like it very much*). The target images were abstract drawings (e.g., Chinese ideograms), which had been rated as neutral on both positive mood and liking scales (e.g., Mikulincer et al., 2001). Before the presentation of each target image participants were exposed to either a subliminal [brief exposure without conscious awareness of the participant, for 22 milliseconds (ms)] or a supraliminal (presented for 500 ms) prime. Three types of primes were used (attachment security, attachment insecurity, and neutral words). Thus, the design was 2 (levels of presentation) by 3 (type of primes), within subjects. The attachment-related prime words had been used in previous studies to activate attachment-related cognitions (e.g., Edelstein & Gillath, 2008). Four words were used for each prime category and included: attachment security (*comfort, embrace, love, support*), attachment insecurity (*loss, lonely, rejected, abandon*), and neutral (*desk, umbrella, table, chair*). Participants first completed 10 practice trails to familiarize themselves with the task and the response box. Each participant then completed two blocks of trials, receiving subliminal priming, followed by two blocks of trials receiving supraliminal priming. The inter-trial-interval (ITI) in the task varied between 1000, 3000, and 5000 ms in a pseudo-random way (i.e., 70% of the time the ITI was 1000 ms, 20% of the time the ITI was 3000 ms, and 10% of the time, the ITI was 5000 ms), to fit with the fMRI event-related design and the repetition time (TR) of 2 s (see Figure 1).

When a prime is presented, even for as little as 22 ms, the afterimage may temporarily remain active in the peripheral parts of the visual system, allowing people to recognize it and thereby interfere with the subliminal priming procedure. To avoid this problem, each prime word was preceded (500 ms for subliminal, 250 ms for supraliminal) and followed (478 ms for subliminal, 250 ms for supraliminal) by a mask consisting of a series of Xs. Each trial began with a fixation cross to orient the participants to the center of the screen. To allow for effective modeling of the hemodynamic response, the display time for the fixation cross was jittered, such that it appeared on the screen for two, four, or six seconds. E-Prime software was used to present the stimuli and maintain synchronicity with the scanner (Psychology Software Tools, Inc.). Participants observed the screen containing the stimuli via a mirror that was placed on the head coil.

fMRI Data Acquisition and Analysis

Brain images were acquired at the Hoglund Brain Imaging Center at the University of Kansas Medical Center, on a 3T Siemens Allegra scanner. Each participant received padding around the head to increase comfort and minimize head movement during the scanning procedure. Prior to the functional series, T1-weighted anatomical images were acquired with a 3D MP-RAGE sequence [TR/echo time (TE) = 23/4 ms, flip angle = 8°, field of view (FOV) = 256 mm, matrix = 256 x 192, slice thickness = 1 mm). This scan was coregistered to the functional scans during preprocessing. Following structural scanning, four gradient echo blood oxygen level dependent (BOLD) scans were acquired in 34 contiguous oblique axial slices, at a 40º angle (TR/TE = 2000/30 ms, flip angle = 90°, FOV = 192 mm, matrix = 64 x 64, slice thickness = 3 mm). To optimize OFC signal by minimizing susceptibility artifact, all participants were positioned in the scanner such that the angle of the AC-PC plane was between 17° and 22° in scanner coordinate space. This angle was verified with a localization scan.

Data were preprocessed with SPM8 (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, London, UK) on the Matlab 7.4 platform (Mathworks Inc., Natick, MA). All 135 scans in each of the four blocks of trials that were used for the analysis were first manually reoriented to the AC-PC. To correct for head motion during scanning, scans were submitted to realignment with a 6 parameter (rigid body) spatial transformation. The four blocks of scans were entered as four blocks (termed “sessions” in SPM) for realignment. The first scan in each session was first aligned to the first scan of the first session. Then the remaining scans were aligned within-session to the first scan in that session and a mean image was created. After realignment, each participant’s T1-weighted anatomical image was co-registered to the mean of the realigned BOLD images. The coregistered image was then segmented according to the standard procedure in SPM8 (Ashburner & Friston, 2005). The functional images were then normalized and resampled at a resolution of 3 × 3 × 3 mm cubic voxels. The normalization procedure warps the images from each participant so that they are all defined within the same parameters. The normalized images were then smoothed using an 8 mm full width at half maximum Gaussian kernel to improve the signal to noise ratio. Preprocessing steps were checked by visually inspecting images using Check Reg. One participant had significant loss of the posterior section of the brain during functional scans, affecting normalization. As a result, this participant was dropped from the analysis.

For the model, the onset times of each fixation and prime were modeled as single events with durations of zero. The fixations were included in the model to represent a baseline comparison for the primes. Because the order of prime presentation and ITIs were randomized for each participant, a unique design matrix was created for each participant. Contrasts for *security* > *neutral* and *security* > *insecurity* were created for each participant. These contrasts were then taken to the second level for group analyses. The Talairach Daemon Client was used to aid in determining the specific regions corresponding to the coordinates provided by SPM (Version 2.42, Lancaster et al., 2000).

Region of interest (ROI) analysis was performed using the Marsbar toolbox for SPM8 (Brett et al., 2002; http://marsbar.sourceforge.net/). Anatomical ROIs provided by Marsbar were selected based on the literature review for the OFC, superior temporal gyrus, fusiform gyrus, and the caudate. Following Aron and colleagues (2005), I also created an ROI for the VTA, by generating a 4 mm sphere around the coordinates, 0 -10 -10, using Marsbar. For each ROI mean contrast values indicating BOLD signal intensity for the contrast of interest were extracted. These contrast values were then used in correlational analysis to determine signal-change associations with self-report attachment measures.

Results

Behavioral Data

Based on previous behavioral studies of the effects of security priming, the liking ratings of the images were expected to be higher following the security prime in comparison to the insecurity and neutral primes. Because subliminal and supraliminal primes have been shown to have similar effects for security enhancement, they were not expected to differ (e.g., Mikulincer & Shaver, 2001). To determine whether the security prime increased within subjects liking ratings of the neutral images, a 2 (presentation level: subliminal vs. supraliminal) by 3 (prime type: secure, insecure, neutral) repeated measures analysis of variance (RM-ANOVA) was conducted. The 29 participants who were included in the fMRI analysis were included in the behavioral analysis, as well. The Huynh-Feldt outputs are reported, which adjust for the violation of the sphericity assumption. As expected, the RM-ANOVA revealed a significant effect of prime $F(1.74, 28) = 6.33$, $p = .005$, partial $\eta^2 = .18$. The neutral images were rated higher after the security primes ($M = 2.43$), than after the insecurity ($M = 2.30$) and neutral ($M = 2.35$) primes (ps $< .05$). The insecurity and neutral prime conditions did not differ ($p > .5$).

The main effect of prime, however, was qualified by a significant interaction with presentation level, $F(1.47, 28) = 6.00$, $p = .010$, partial $\eta^2 = .18$ (see Figure 2). To understand the 2-way interaction, the RM-ANOVA was conducted separately for the subliminal and supraliminal level. The comparison of liking of the images following the subliminal primes revealed no significant differences between the prime types, $p > .5$. Next, the liking ratings following the supraliminal primes were tested. The analysis revealed a significant effect of prime type, $F(1.37, 28) = 7.73$, $p = .004$, partial $\eta^2 = .22$. Pairwise comparisons showed that the security prime (M = 2.48) resulted in higher liking ratings for the images, than the insecurity (M = 2.22) and the neutral (M = 2.29) primes, ps $< .05$. The insecurity and neutral prime conditions did not differ ($p > .5$). The lack of a difference between priming conditions at the subliminal level was unexpected. While significant effects of similar, subliminal security primes have been found, the different findings in this case may be attributable to the environment, as no previous subliminal security priming study has been conducted inside a scanner. Also, the small sample, due to the expensive nature of fMRI, may not have allowed enough power to capture the differences in the more subtle, subliminal priming condition.

Differences across presentation levels for each prime type were examined with paired samples t-tests. Results showed that the liking of the images did not differ for subliminal versus supraliminal security primes, $t(28) = 1.43$, $p > .05$. Additionally, the liking ratings following the supraliminal neutral prime were not lower in the supraliminal versus the subliminal condition based on a Bonferroni correct *p*-value for multiple tests (.013), $t(28) = -2.15$, $p = .041$. Following the insecurity prime, the images were rated as less liked in the supraliminal condition versus the subliminal condition, $t(28) = -3.15$, $p = .004$. This suggests that in comparison to the subliminal primes, the supraliminal primes were more effective at decreasing liking in the insecurity conditions.

Potential moderating effects of attachment anxiety and avoidance at each level of presentation were also examined by adding the dispositional attachment scores as covariates in the analysis. While there were no differences among liking ratings at the subliminal level, there was a significant within subjects interaction between attachment anxiety and prime type, $F(2, 52) = 7.40$, $p = .001$, partial $\eta^2 = .22$. Thus, the hypervigilance of people high in attachment anxiety may have affected responses at the unconscious level. At the supraliminal level, there were no within subjects interactions with attachment style.

Functional Data

Whole brain comparisons. In the first set of analyses I investigated the activation associated with enhanced security. To minimize the chances of false positive in our analyses, an inclusive masking procedure was implemented to restrict the focus on areas involved with the priming procedure. This analysis technique followed previous studies and allowed us to restrict the likelihood of detecting activation in areas that were not actually associated with security priming (e.g., Ortigue et al., 2007). To create the inclusive masking, we first ran a one sample t-test contrasting *all supraliminal primes* > *all fixations*. The contrast had a threshold of $p < .001$, uncorrected. This contrast, which included all the areas of the brain that were activated during priming, was used as the inclusive mask in subsequent analyses. I next created contrasts for *security* > *neutral*, and *security* > *insecurity*. The contrast with neutral prime words was included to examine the effect of security as compared to a baseline. Both conditions contained the presentation of words to control for more general priming effects, but the security priming condition was expected to involve increased activation in areas related to affect, cognition, and motivation/behavior. The insecurity condition was also used as a comparison because, whereas it was expected to activate similar areas associated with the attachment system and relational processes as the security prime, the comparison of security to insecurity was expected to reveal brain activation unique to the sense of security, rather than more generally to the attachment system. The brain areas that are reported below were significant at the $p < .01$ level for ten contiguous voxels (Ortigue et al., 2007).

Supraliminal primes. The contrast *security* > *neutral* priming revealed areas of brain activation positively associated with the security prime (see Table 2). These areas included the right medial frontal gyrus [Brodmann Area (BA) 6] and left inferior frontal gyrus (orbital, BA 47; see Figure 3), the right precentral gyrus, and the left putamen (see Figure 4).

Because both the attachment security and insecurity primes may activate an attachment-related neurological network that includes emotion and regulatory processes, a *security* > *insecurity* contrast was conducted to show areas of activation specific to security-related priming. Areas with increased activation when exposed to the security prime included the right postcentral gyrus, the right inferior temporal gyrus (BA 19), as well as the right middle frontal gyrus (BA 6). In addition, the security prime activated the bilateral cerebellum and fusiform gyri (BA 37; see Figure 5).

Subliminal primes. Although the behavioral task did not demonstrate differences in response among the different subliminal primes, an exploratory analysis was conducted to identify any brain areas activated during presentation of the subliminal primes. Even though the small sample size or the scanning environment may have affected the ability to detect differences at this level, the brain may have been responsive to the primes. The same inclusive masking procedure was implemented (using all subliminal primes). With the use of the inclusive mask, contrasts were created for *security* > *neutral* and *security* > *insecurity*. The brain areas that are reported were significant at the $p < .01$ level for ten contiguous voxels (see Table 2).

First, security priming was compared to neutral priming. Areas activated when exposed to the security prime involved prefrontal areas including the right superior frontal gyrus (BA 6), right medial frontal gyrus (BA 32), left middle frontal gyrus (BA 9), and left OFC. In addition, the right angular gyrus and the right inferior parietal showed increased activation to the subliminal security prime. Activation in BA 6 and in the OFC was similar to that at the supraliminal level. Next, a *security* > *insecurity* contrast was conducted. Areas activated when exposed to the security prime included right middle frontal gyrus (BA 6, 8) and right inferior parietal (BA 40). The activation in the middle frontal gyrus (BA 6) was similar to that in the supraliminal level.

Activation correlations with attachment style. Attachment style was found to affect sensitivity to attachment-related material, and a few studies have already showed that attachment style may moderate the effects of security priming (e.g., Mikulincer et al., 2002; Cassidy et al., 2009). In addition, there was an interaction between attachment anxiety and priming at the subliminal level. Therefore, I tested whether the pattern of brain responses to security inducing stimuli differed based on attachment style. To do that attachment anxiety and avoidance were analyzed separately as covariates in exploratory whole brain analyses. Thus, each contrast was examined with a one sample t-test with the attachment score included as a covariate in the analysis. In addition, state attachment security was analyzed because the ECR does not have a measure of attachment security and I was interested in determining how current feelings of security would affect brain response to security inducing stimuli. The activation of people high in state security was expected to mimic the whole brain findings, in that they were expected to show increased activation in the areas shown to be activated in response to the security prime.

Because people high in anxiety tend to hyperactivate the attachment system in response to attachment-related stimuli, they were expected to show increased response to the attachment-related stimuli as compared with people low in anxiety. Moreover, people high in attachment anxiety tend to be hypervigilant to attachment-related stimuli and as a result they may exhibit increased activation even in the subliminal level in response to the attachment-related primes (Gillath et al., 2005). Based on previous research (e.g., Gillath et al, 2005) this activation was expected to focus around emotion- and control-related areas (e.g., anterior temporal pole and OFC).

Because people high in avoidance tend to deactivate the attachment system in response to attachment related stimuli, they were expected to show decreased response to the attachment-related stimuli as compared with people low in avoidance. However, because of their negative models of others, and tendency to avoid intimacy and closeness, at least in the supraliminal level I expected to see activation in negative-emotion-related areas, as well as regulation areas (such as the amygdala and medial frontal cortex or OFC). As in the previous analysis, the contrast indicating activation in response to all primes was used as an inclusive mask.

***Correlations with state attachment security*.** Security priming was first compared to neutral priming with the *security* > *neutral* contrast at the supraliminal level (see Table 3). Areas of activation correlated with state security included the right inferior parietal (BA 40) and the right cingulate gyrus (BA 24). Correlations with security in response to the supraliminal *security* > *insecurity* contrast were next tested. Significant correlations were found in the right inferior frontal gyrus (BA 9), bilateral inferior parietal (BA 40), right postcentral gyrus, left cerebellum, right middle frontal gyrus (BA 6, 42), and the left middle temporal gyrus (BA 37).

Next, activations in response to the subliminal security primes were examined. Security priming was first compared to neutral priming with the *security* > *neutral* contrast. Activation associated with state security included the right precentral gyrus (BA 6), right insula (BA 13), right superior frontal gyrus (BA 6), and the right putamen. Next activation in response to the *security* > *insecurity* contrast was explored. State security was correlated with activation in the left cerebellum and the left fusiform gyrus (BA 19).

Correlations with attachment anxiety. Associations between dispositional attachment anxiety and security priming were first compared to neutral priming with the *security* > *neutral* contrast at the supraliminal level. Areas of activation correlated with attachment anxiety when exposed to the supraliminal security prime included the left postcentral gyrus, left inferior parietal (BA 40), and left thalamus (see Table 4). Activation in response to the *security* > *insecurity* contrast was next tested at the supraliminal level. Areas of activation correlated with attachment anxiety included the precuneus (BA 7), left supramarginal gyrus, and left cerebellum (see Table 4).

Next, activations in response to the subliminal security primes were examined. Security priming was first compared to neutral priming with the *security* > *neutral* contrast. Results from the contrast revealed no areas of activation correlated with attachment anxiety. Activation in response to the *security* > *insecurity* contrast was then tested. Areas of activation correlated with attachment anxiety when exposed to the subliminal security prime included prefrontal regions, such as bilateral superior frontal gyrus (BA 8), right OFC (BA 47), bilateral middle frontal gyrus (BA 6, 8), and right medial frontal gyrus (BA 10). In addition, the right subcallosal gyrus, showed increased activation (see Table 4).

Correlations with attachment avoidance. For the *security* > *neutral* contrast at the supraliminal level, areas of activation correlated with attachment avoidance included the left parahippocampal gyri (BA 34), bilateral amygdala, left insula, middle and superior temporal gyri, middle frontal gyrus (BA 6), and left cerebellum (see Table 5). For the *security* > *insecurity* contrast at the supraliminal level, areas of activation correlated with attachment avoidance included the left amygdala, left STG, left parahippocampal gyrus (BA 35), left cerebellum, subcallosal gyrus (BA 25), and right OFC (BA 47; see Table 5). There were no areas correlated with avoidance at the subliminal level with either contrast.

Regions of interest (ROIs). In addition to examining the activation associated with the security prime in areas across the whole brain related to the priming task, specific a priori defined ROIs were explored. ROI analysis allows for the ability to target specific areas of the brain and test if activation in those areas differs as a result of condition. The ROI analysis allowed me to further explore potentially important areas that were defined in the introduction.

Previous fMRI research on attachment has shown that brain activation patterns in response to attachment-related stimuli are moderated by individual differences in attachment style (e.g., Gillath et al., 2005). However, as mentioned previously, the studies that have been done so far have focused primarily on activation patterns associated with attachment insecurity. The goal of the current ROI analysis was to determine if BOLD signal in a priori defined areas was also moderated by individual differences in attachment, specifically examining people’s current feelings, or levels of state attachment security, avoidance and anxiety. Because the whole brain contrasts explored the security primes in relation to the neutral primes, for the ROI analysis security was explored in comparison to a baseline level of activation removed from the prime as defined by the fixation.

The ROIs were selected based on previous research, to highlight security associations with positive affect, regulation and social information processing, and motivation. Thus, because the sense of security is proposed to impart its effects through multiple components, I selected ROIs known to be functionally associated with the proposed components. Specifically, for the affective component, the caudate and the VTA were examined, for the cognitive component the OFC , the superior temporal gyrus, and the fusiform we examined as they may be related to activation of IWMs. The caudate and VTA were also chosen to represent the behavioral component as they are known to be part of a reward-motivation system, thus they were expected to increase positive affect as well as motivate response. Once the contrast values were extracted for each participant for each ROI, correlations among the attachment scores and activation related to the ROIs were examined.

First tests of the difference in activation in the ROIs as a result of the contrasts were examined. When corrected for multiple comparisons only the left fusiform, $t(28) = 9.72$, $p < .001$ and the right fusiform, $t(28) = 10.01$, $p < .001$, were significantly different in the *security > fixation* contrast.

***Correlations among attachment factors and activation in ROIs*.** The first set of analyses examined the correlations among state attachment anxiety, avoidance, and security, and contrast values for *security > fixation*. This analysis explores whether attachment scores are associated with increased activation in the ROIs in comparison to baseline-level activation. The analysis revealed that state avoidance was negatively associated with activation in the left caudate (r = -

.35, p = .06) when people were exposed to the security prime as compared with the fixation. And while it did not reach significance, state avoidance was also negatively associated with activation in the left fusiform gyrus (r = -.31, p = .10). State anxiety was associated with less activation in the VTA (r = -.38, p = .04) in response to the security prime (see Figure 2). The next analysis examined the correlations among the state attachment factors and contrast values for *security* > *insecurity*. The results showed that the differences in activation in the ROIs between the security and insecurity primes was not associated with state attachment scores for anxiety, avoidance, or security.

Discussion

The goal of the current study was to test the conceptualization of attachment security as involving three components: affective (e.g., positive mood, relaxation), cognitive (e.g., IWMs including memories, strategies, and resources—regulation and processing), and behavioral (e.g., motivation and behavioral tendencies). I tested this by momentarily enhancing people's sense of security with priming and examining the brain activation associated with this enhancement. A secondary goal was to test the effects of attachment-related individual differences on the sense of security and its enhancement. As expected the presentation of security primes resulted in activation in areas of the brain related to positive affect, regulation and social information processing, and motivation. Consistent with the proposal that security enhancement provides mental resources that equip a person with additional tools to use in attachment-related cognitions and decision-making, a lot of the activation I found was in regions previously associated with regulation and processing (e.g., OFC). As compared with both neutral, and negative attachment-related emotional stimuli, security primes were associated with increased activation in emotion, regulatory, and motivational areas, supporting security's resource-related role.

Affective Component

Comparing the security prime to the neutral prime showed that security activated areas involved in the processing of positive affective information such as the precentral gyrus (Teasdale et al., 1999), which is consistent with the affective response of security priming. Security was also associated with activation in reward-related areas. Although the predicted areas of caudate and the VTA were not significantly activated, the putamen—a related area—was activated when people were exposed to a supraliminal security prime. Activation in the putamen has been previously associated with positive emotion, including romantic love (e.g., Bartels & Zeki, 2000; Hamann & Mao, 2002). In addition there was activation in multiple areas of the cerebellum, in comparison to the insecurity prime. The cerebellum has been shown to be important in the interpretation and experience of positive affect in response to positive stimuli, including love (e.g., Bartels & Zeki, 2000; Schutter & van Honk, 2005; Turner et al., 2007).

The security prime also activated, at the subliminal level, the inferior parietal and the middle temporal gyrus, which were shown by Aron and colleagues (2005) to be associated with the love response at higher levels among people who had been in the relationship for a longer period of time. The activation I found in these areas is consistent with the notion that one's love for or attachment to a person tends to increases with time. Thus, the overlapping activation in these areas in response could indicate that security priming leads to the positive feelings associated with long-term bonds.

These findings support the idea that there is an affective component of security. Based on the findings with romantic love and oxytocin, security priming may similarly lead to a positive or rewarding experience which affects motivational processes. Other prefrontal areas important in reward processing and evaluation may be related to the affective experience as well (e.g., medial frontal gyrus; Ochsner & Gross, 2005). Thus, while increased activation was not found in areas like the caudate or VTA, activation in the medial frontal gyrus could be related to appraisal and regulatory processes as a result of identifying the stimulus as positive. While many of the affective areas mimic those associated with love—security may also involve a reward-motivational process—at the cognitive level security is set apart.

Cognitive Component

The medial frontal gyrus, the OFC (e.g., Ochsner & Gross, 2005; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004) and the precentral gyrus (e.g., Hopfinger, Buonocore, & Mangun, 2000) were all found in multiple studies to be associated with cognitive control and regulatory processes. Specifically, higher order cognitive processes including attentional control, emotion regulation, and appraisal were found to be inextricably linked with activation in the medial frontal gyrus and OFC (Ochsner & Gross, 2005). Exposure to the security prime as compared with the neutral prime in the current study was, as predicted, associated with higher activation in these areas. These findings lend support for the idea that security priming leads to the activation of a secure IWM and provides a person with additional resources to evaluate and respond to the environment. Thus, security may increase regulatory abilities, and increase the ability to focus on the task at hand and perceive the situation in line with a more secure IWM (through reappraisal).

Moreover, when comparing security and insecurity primes (which also involved attachment-related words that should activate emotion and regulatory processes), the security prime was still associated with increased activation in control and regulatory areas of the brain. These included the right postcentral gyrus known to be associated with attentional processes, (Tomasi, Chang, Caparelli, & Ernst, 2007), the inferior temporal gyrus known to be associated with emotion regulation (McRae, Ochsner, Mauss, Gabrieli, & Gross, 2008) and cognitive reappraisal (Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008), and the middle frontal gyrus, also associated with emotion regulation, social processing, and empathy (Lawrence et al., 2006; Ochsner, Bunge, Gross, & Gabrieli, 2002). Activation in the cerebellum, which has been linked with emotion and cognitive response (Phan, Wager, Taylor, & Liberzon, 2001) as well as regulation (Schmahmann, 2000) was also increased. Additionally, and as expected, security resulted in increased activation in the fusiform gyri, known to be related to memory retrieval (Wiggs, Weisberg, & Martin, 1999), and associated with love as measured by response to the name of a romantic partner (Ortigue et al., 2007).

These findings in comparison to the insecure prime provide additional support for security's role as a mental resource allowing for better regulation and control. A person's response to the insecurity primes would be expected to result in regulatory processes as well—attempts to deal with the resulting negative affect or cognition. However, the current study found that the security prime resulted in activation in regulatory areas beyond those in the insecure condition. The activation of areas associated with memory and reappraisal supports the link between security priming and activation of secure IWMs. When confronted with a security prime, people may seek a mental representation of their attachment figure and retrieve previous experiences of security. By accessing the secure working model, they are opened up to greater abilities to processes social information, such as understanding the needs and intentions of others, and have a greater decision-making ability in regard to cognitive reappraisal and behavioral tendencies. Taken together this activation supports the proposal that security involves a cognitive component.

Behavioral/Motivational Component

The putamen mentioned above with regard to positive affect, is known to be associated with reward and has been proposed to be a central part of the dopaminergic reward system underlying motivated response (Kirsch et al., 2003). In addition the putamen contains a high density of oxytocin receptors, which in non-human animals has been shown to be important in motivating social and bonding behaviors (Bartels & Zeki, 2004; Carter, 1998). This activation suggests that security is associated with motivation or behavioral processes. In addition, BA 6, which was activated in response to security, is important for behavioral planning (Fincham, et al., 2002) and response to motivating stimuli (Kirsch et al., 2003). Similarly, the medial frontal gyrus is involved with the anticipation of outcomes, which may result in the role of the security prime in behavioral response (Amodio & Frith, 2006). Thus the increased activation in brain areas linking reward and motivation, and in outcome anticipation may be indicative of security's ability to affect behavioral choices, such as reporting increased liking of the images in the current study.

Taken together the whole brain analysis provides evidence for the conceptualization of security as including affective, cognitive, and behavioral/motivational components. While all three components are represented, there is a strong emphasis on cognition and resources. The results show that security priming involves regulatory processes that have not been associated with exposure to romantic love cues—or response to a romantic partner's name or picture, who may serve as attachment figures. Previous fMRI studies investigating love have characterized love as an affective state and shown that the experience of love is associated with neurological mechanisms involved mainly with emotion, reward, and motivation. Researchers, including Bartels and Zeki (2000), showed that love activated areas of the brain that are rich in oxytocin and vasopressin receptors—which are known to be important in bonding behaviors in nonhuman animals—and have proposed that love involved a reward-motivation system (see also Aron et al., 2005). Thus, romantic love involves emotions, which are linked with reward, and are subsequently motivated to seek these bonding experiences. Security was expected to have similar qualities as love—the involvement of positive emotion and reward—but, was expected to have additional qualities that demonstrate the unique ability of the sense of security to provide mental resources that can be used for processing attachment-related information and improve coping (e.g., self-soothing, emotion regulation, helping others). Thus, security was expected to activate control and regulatory areas of the brain, and the current findings support this conceptualization.

Individual Difference in Attachment Style and the Sense of Security

While not the main focus of the current research, because previous fMRI studies have only investigated attachment-related brain activation in response to threatening or insecurity-related attachment stimuli, the links between attachment style (state security and dispositional insecurity) and security primes were explored. In most behavioral studies even people that are relatively high on attachment avoidance or anxiety still demonstrate the beneficial effects of the security primes. However, it is not known if security primes actually turn them secure momentarily (which should manifest in no brain activation differences between them and less insecure or secure people) or simply allow them to react in a secure-like manner while maintaining their insecurity (differences in brain activation).

For people who were currently high in state security, their brain activation was expected to be similar to that in the whole brain, but demonstrating increased activation in those areas. Consistent with these predictions security was correlated with activation in the medial frontal gyrus, cerebellum, pre- and post- central gyri, the putamen, inferior parietal, BA 6, and the fusiform gyrus. Thus, people high in current feelings of security showed increased activation in areas activated by security priming, providing further support for the role of these areas in the sense of security. Some additional areas were found as well. Thus, state security was also correlated with activation in the middle temporal gyrus and BA 24 in the cingulate. Activation in the middle temporal gyrus was correlated with length of relationship in Aron and colleagues' (2005) study of love and a similar area of the cingulate was activated in response to the love primes in Bartels and Zeki's studies (2000; 2004). Thus these areas could be particularly relevant for the rewarding experience that comes from strong or highly secure attachments as experienced by people feeling especially secure.

The results from the current study demonstrated that attachment insecurity was associated with differences in brain activation in response to security primes. When consciously perceiving the security primes, in comparison to the neutral prime, people who were higher on attachment anxiety had increased activation in areas related to attention (postcentral gyrus) and social perception processes (inferior parietal). In addition, the thalamus, which is often activated in response to emotional stimuli (e.g., Britton et al., 2006) and, in particular, emotionally arousing or intense stimuli (Colibazzi et al., 2010) had higher activation among people high on attachment anxiety when exposed to security primes. This suggests that the security prime may be perceived as especially salient and result in a more intense emotional response among highly anxious people. In comparison to the negative attachment-related stimuli, attachment anxiety was also correlated with higher activation in the precuneus, which is associated with episodic memory retrieval and processing of self-relevant information (e.g., Cavanna & Trimble, 2006), the supramarginal gyrus, which is involved in reappraisal (Ochsner et al., 2002), and the cerebellum.

These patterns of activation are consistent with the hypervigilant nature of people high on attachment anxiety. People high on attachment anxiety typically have a strong desire for closeness and intimacy—they are seeking a sense of security—but they tend to have a low opinion of themselves as deserving of such a relationship, so tend to fear or expect rejection from partners. The prospect of security should be especially salient for highly anxious people, and the brain responses in the current paper are in line with this. When highly anxious people were presented with security-related stimuli they showed greater activation in attention-related areas and a more intense emotional brain response. In addition, the security primes may lead to a search for previous secure experiences they have had—activating the secure IWM which may direct their subsequent behavior. While it is expected that activating a security-related cognitive network is a general process, not specific to people high in anxiety, the hypervigilance of anxiously attached people may lead to a more intense search for security-related models or memories or alternatively having a hard time engaging in these activities.

The hypervigilance of people high on attachment anxiety was additionally demonstrated by the increased levels of activation in response the subliminal security primes as compared with non-anxiously attached people. When exposed to the security as compared with the insecurity attachment primes, attachment anxiety was positively correlated with frontal regulatory regions, such as the superior frontal gyrus, the OFC, middle frontal gyrus, and the medial frontal gyrus, suggesting that anxiously attached people are making increased attempts to regulate their responses to the security prime. In addition, an area associated with sadness, the subcallosal gyrus, showed increased activation (Phan et al., 2002). This suggests that people high on anxiety may experience a conflicting response to the security prime even at the subliminal level (e.g., security sounds nice, but can I really achieve it?). This could result in their increased attempts at regulation—to overcome the negative affect. Overall, the links between attachment anxiety and security priming at the subliminal level support the idea that they are hypervigilant for signs of love being taken (rejection/insecurity) or given (security).

The results also showed associations between attachment avoidance and response to the security primes, though they were only at the supraliminal level. When compared to neutral primes, people high on avoidance, showed increased activation in the parahippocampal gyrus, which has been repeatedly associated with memory processes including encoding and retrieval (e.g., van Strien, Cappaert, & Witter, 2009). This suggests that they are making increased memory retrieval attempts, perhaps reflecting a lack of easily accessible secure models.

In addition, avoidance was correlated with activation in areas linked with emotion, including the amygdala, which is typically activated in response to salient emotional stimuli and uncertainty, but in particular to aversive emotional stimuli (Davis & Whalen, 2001). In addition, avoidance was correlated with the insula, which is involved in emotional response, but also evaluation of emotional stimuli (Berntson et al., 2011) and disgust (e.g., Wicker et al., 2003). These findings suggest that avoidant people may have at least an initial reaction to security that is negative. Avoidance was also associated with the middle and superior temporal gyri, which are associated with regulation and social processing (Britton et al., 2006; McRae et al., 2008), and the cerebellum. Thus, even though they have experience some level of negative response, the increases in regulatory and social processing areas may provide them with the ability to overcome the initial reaction and ultimately respond in a more secure way.

In comparison to the negative attachment-related stimuli, areas of activation correlated with attachment avoidance included, again, the amygdala and cerebellum, but also the superior temporal gyrus (related to social perception), the parahippocampal gyrus (related to memory), and the OFC (related to regulation). In addition the subcallosal gyrus (BA 25) was activated which has been linked to avoidant people's ineffective suppression or inhibitory processes (Gillath et al., 2005). These results suggest that the security prime words were considered distressful, even in comparison to insecure primes, for people high in avoidance. Since avoidant people still tend to show beneficial effects of security prime, this initial aversive reaction may be overcome by increased efforts to regulate or suppress this response and access security-related models. This explanation is speculative, however, as the current analysis does not allow for an understanding of the order or timeline of activation that takes place.

Attachment avoidance is characterized by deactivation in response to attachment-related stimuli and a desire to avoid intimacy and closeness. However, in behavioral studies, people high in avoidance still tend to show effects of security priming. This suggests that in a subliminal level avoidant people can suppress these topics or information. In line with this idea the current null findings from the subliminal level suggest successful avoidance of the security-related stimuli by avoidantly attached people.

The ROI analysis provided further information about individual differences. For example, activation in the caudate and the fusiform gyrus, which are areas consistently associated with romantic love and oxytocin receptors (the caudate) in previous studies, was found to be negatively associated with state avoidance. Thus, people high on state avoidance showed less activation in an area thought to be linked with the reward-motivation system and in an area associated with social processing and representation of others (fusiform). These findings indicate that current feelings of attachment avoidance may block some of the positive responses to security primes through deactivating strategies, leading to lower feelings of reward and activation of internalized attachment figures. In addition, state anxiety was associated with less activation in the VTA. Because people high in anxiety tend to have a strong desire for secure relationships, they may be expected to experience increased reward when security is offered. However, this decrease in activation could reflect the conflict regarding the potential for security along with the potential for rejection or being hurt. Thus, the lower VTA activation could result in less motivation for behavioral responses in line with secure IWMs, which may help to explain some of the previous interactions among security priming and anxiety (e.g., Mikulincer et al., 2011).

Differences in Presentation Level

Although also not a main goal of the current work I was able (as briefly mentioned above) to compare subliminal and supraliminal security priming in the current study. Previous laboratory studies have demonstrated effects of the subliminal presentation of security-related words (e.g., Gillath et al., 2008); however, there have been no previous studies investigating the effects of subliminal security priming using neuroimaging. The current study did not find behavioral effects at the subliminal level. The lack of effects could be explained by the priming method (words) not being strong enough (as compared to images, particularly in the scanner in which the stimuli are displayed on a small mirror), the strong anxiety due to being in a scanner environment, which reduced the subtle subliminal effects, and the small sample size. However, even though the behavioral task did not demonstrate differences in response among the subliminal primes, an exploratory analysis showed that even at an unconscious level, the security prime included multiple prefrontal areas related to regulatory processes.

During subliminal presentation, increased activation was found in the superior frontal gyrus, medial frontal gyrus, middle frontal gyrus, and OFC, similar to that found at the supraliminal level. These findings reveal that the regulatory processes involved in security priming at the supraliminal level are similar to those at the subliminal level. A lack of activation in some of the emotion and reward-related areas may however have led to less behavioral response tendencies in the current study. Because of the lack of behavioral findings, strong conclusions about the potential roles of the different levels of presentation cannot be made, but my finding do indicate a similar process taking place at the subliminal level which is consistent with studies showing the effectiveness of both methods.

Limitations and Future Directions

While the current research was able to effectively demonstrate neurological mechanisms underlying attachment security prime, there are some limitations. One limitation is that the current study could not contain all potential controls and did not contain a priming condition to control for responses general to positive affective stimuli. Because of this, I am unable to definitively rule out potential overlap in brain activation among positive affective priming and security priming, more specifically. However, in support of the current findings, the response to security priming was compared to brain areas activated in response to romantic love (a positive emotion, reward-related experience) in previous studies. Some areas of activation were similar, which was expected, but security additionally demonstrated BOLD response in areas not previously associated with romantic love. In addition, behavioral studies have demonstrated that the effects of security priming exist above and beyond positive affect (e.g., Mikulincer et al., 2005).

Another limitation concerns the lack of significant behavioral responses at the subliminal level of presentation. While the priming methods used have been successful outside the scanner, the subliminal prime was not strong enough to influence behavior or the low number of participants restricted the ability to detect the effects of the prime. While differences in BOLD response were found in response to the subliminal prime, they should be taken with some caution as they were not replicated at the behavioral level.

A final limitation that I will mention involves the selection of ROIs and the lack of findings with regard to state attachment style. I attempted to narrow down, based on a literature review of neuroimaging findings related to the three proposed components, potential areas likely to be related to enhanced security. These ROIs were derived in an a priori manner; however, they revealed few significant results. One possibility is that the areas chosen really are not strongly linked with security enhancement or attachment process and there were other areas that would have been better to explore, such as the putamen or medial frontal gyrus. Another potential explanation is that the use of quickly presented words as the priming method was not strong enough to show effects in this analysis. For instance, many studies showing effects of individual differences in brain activation involve the presentation of highly salient pictures or of prolonged displays of emotionally relevant stimuli (e.g., 30 s, Aron et al., 2005). Thus, the ROIs chosen may not be necessarily ruled out as areas potentially associated with the sense of security.

Some of these limitations can be addressed in future studies. For instance, in order to isolate security as unique, it should be directly compared to other positive or motivating stimuli. A similar study could involve the presentation of positive affective words (such as happy and joy) as well as motivational words (such as money or win). Being able to directly compare the brain response among security and these other controls would allow for greater confidence that the proposed three component model is unique to security.

A future study could also implement more salient security-related stimuli. One way this could be achieved is by presenting the words for a longer period of time (e.g., 2 s) or images depicting secure scenarios. The images, especially at the subliminal level, may provide a stronger method for achieving results of security priming in the scanner. Another approach could more directly assess behavior in response to the prime in the scanner. In the current study, because participants' only behavior involved pressing a button for liking, determining the brain areas involved in secure behavioral tendencies in the real world may be especially challenging. Implementing a priming task in the fMRI environment in which participants can interact with another person and choose behavioral responses (such as whether to trust in a game or help someone in a virtual environment) can provide further insight into the ways that security priming affects the neurological processes underlying behavior.

Conclusion

The sense of attachment security is an integral component of attachment theory. Over the last few decades the numerous benefits of the sense of security have been demonstrated. Moreover, in more recent years attachment researchers have begun to manipulate the sense of security and have demonstrated that security can be experimentally enhanced, leading to beneficial outcomes, even for people who have a relatively insecure attachment style. However, while many of the beneficial effects of security have been made apparent, an understanding of what exactly security is has not been clarified.

Neuroimaging provides a unique opportunity to explore the potential processes underlying the sense of security. Thus, while saying people are secure theoretically means that they have at their disposal a variety of resources designed to promote self and relationship well-being, the current research was able to show that security enhancement does indeed seem to provide people with additional resources. The resources were demonstrated by increased activation in areas key for attention and emotion regulation in response to the security prime. In addition, security was shown to increase activation in areas related to reward and behavioral motivation. My findings also demonstrated that the sense of security shows distinctness from romantic love, and provides more than reward and motivation to form and maintain attachments. I also investigated individual differences. While many behavioral studies demonstrate that security priming affects both secure and insecure people in a similar way, the current research revealed that there are differences in underlying neurological processes associated with security priming. Thus, the experience of security enhancement is not the same for everyone—people tend to have different processes to adjust for the underlying insecurities they experience.

In all, many of the brain-based findings in the current study provide support for previous behavioral studies and the proposed approach that there are affective, cognitive, and behavioral components of security priming. By using fMRI the current research was able to demonstrate that all three of these components take place together. These findings are in support of an understanding of the sense of security as involving affect, cognition, and behavior, and that each is an important component of the experience of the sense of security. Security, therefore, seems to be a mental resource derived from multiple sources that leads to positive outcomes and enhanced well-being.

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Table 1
Potential brain areas associated with the components of the sense of security

Predicted Region	Areas Found in Current Analyses
Affective	
Anterior cingulate cortex	*
Caudate	
Globus pallidus	
Insula	*
Putamen	*
Ventral tegmental area	
Cognitive	
Angular gyrus	
Anterior cingulate cortex	*
Fusiform gryus	*
Hippocampus	
Medial frontal gyrus	*
Middle frontal gyrus	*
Orbitofrontal cortex	*
Posterior cingulate	
Superior frontal gyrus	*
Superior temporal gyrus	
Precentral gyrus	*
Behavior/motivation	
BA 6	*

Caudate		
Putamen	*	
Ventral tegmental area		

Note: The areas listed are not presumed to be indicative only one component, so are artificially separated here.

Table 2

Whole brain analysis for contrasts of interest

Region	~BA	Coordinates of peak activity	t	Z-score
Supraliminal security > supraliminal neutral contrast				
Medial Frontal Gyrus R	6	3 -22 55	3.39	3.07
	6	12 -25 58	2.25	2.97
Inferior Frontal Gyrus L Orbital	47	-51 29 -11	2.85	2.65
Precentral Gyrus R	6	24 -19 58	2.87	2.66
Putamen L		-21 -1 -5	2.94	2.72
Supraliminal security > supraliminal insecurity contrast				
Cerebellum L Declive		-9 -70 -20	3.18	2.92
L Pyramis		-3 -67 -26	3.26	2.97
R Declive		9 -70 -20	3.18	2.92
R		24 -40 -26	2.88	2.68
Fusiform Gyrus L	37	-36 -37 -11	3.52	3.18
R	37	33 -43 -14	3.23	2.96
Inferior Temporal Gyrus R	19	48 -61 -2	3.26	2.97
Middle Frontal Gyrus R	6	30 11 46	2.80	2.61
Postcentral Gyrus R	1	48 -22 55	2.77	2.59
	2	54 -22 49	2.96	2.74
	3	30 -22 46	4.09	3.59
	3	48 -16 49	2.94	2.72

Subliminal security > subliminal neutral contrast				
Inferior Parietal R	40	45 -58 43	2.99	2.76
Medial Frontal Gyrus R	32	18 11 46	2.73	2.55
Middle Frontal Gyrus L	9	-30 23 34	2.57	2.42
Middle Frontal Gyrus L Orbital	11	-30 41 -11	2.59	2.43
Superior Frontal Gyrus	6	24 17 58	3.69	3.30
Subliminal security > subliminal insecurity contrast				
Inferior Parietal R	40	54 -46 46	3.46	3.13
	40	45 -55 40	3.41	3.09
	40	51 -46 37	2.98	2.75
Middle Frontal Gyrus R	6	24 11 61	3.78	3.37
	8	42 17 46	2.95	2.73

N = 29; All reported regions are significant at *p* < .01 for 10 contiguous voxels uncorrected.

Table 3

Correlations with state attachment security in whole brain analysis

Region	~BA	Coordinates of peak activity	t	Z-score
Supraliminal security > supraliminal neutral contrast				
Cingulate Gyrus R	24	3 2 40	2.71	2.60
	24	9 2 46	2.81	2.61
Inferior Parietal R	40	54 -34 40	2.94	2.71
Supraliminal security > supraliminal insecurity contrast				
Cerebellum L Uvula		-12 -61 -29	3.83	3.39
L		-21 -55 -29	3.08	2.83
Inferior Parietal L	40	-57 -25 31	3.25	2.96
R	9	48 5 25	4.11	3.59
	40	54 -34 43	4.09	3.57
	40	39 -31 40	3.23	2.94
Middle Frontal Gyrus R	46	42 35 13	3.45	3.11
	6	27 -1 58	2.89	2.68
	6	24 -7 49	2.79	2.59
Middle Temporal Gyrus L	37	-42 -67 10	3.34	3.03
Postcentral Gyrus R	2	-54 -28 40	3.37	3.05
Subliminal security > subliminal neutral contrast				
Insula R	13	33 8 16	2.82	2.61
Precentral Gyrus R	6	42 2 25	3.61	3.23
	6	54 2 28	3.40	3.07

Superior Frontal Gyrus R	6	21 14 49	3.21	2.93
Subliminal security > subliminal insecurity contrast				
Cerebellum L		-24 -46 -35	3.71	3.31
Fusiform Gyrus L	19	-42 -67 -11	2.77	2.58

N = 29; All reported regions are significant at $p < .01$ for 10 contiguous voxels uncorrected.

Table 4

Correlations with attachment anxiety in whole brain analysis

Region	~BA	Coordinates of peak activity	t	Z-score
Supraliminal security > supraliminal neutral contrast				
Inferior Parietal L	40	-42 -34 31	2.65	2.48
Postcentral Gyrus L	2	-51 -19 28	2.52	2.45
	3	-18 -31 52	3.11	2.85
Thalamus L		-21 -28 4	2.62	2.45
Supraliminal security > supraliminal insecurity contrast				
Cerebellum L		-24 -37 -35	3.30	3.00
Precuneus L	7	-9 -43 46	3.53	3.17
R	19	27 -79 37	2.84	2.63
Superior Occipital R	19	36 -79 31	2.81	2.61
Supramarginal Gyrus L	40	-51 -46 28	4.12	3.60

Subliminal security > subliminal insecurity contrast

Inferior Frontal Gyrus Orbital	R	47	27 23 -20	3.98	3.50
Medial Frontal Gyrus	R	10	12 53 4	3.13	2.87
Middle Frontal Gyrus	L	8	-33 29 46	2.98	2.74
	R	6	48 8 49	2.85	2.64
Superior Frontal Gyrus	L	8	-36 20 52	2.98	2.75
	R	8	30 20 49	4.07	3.56
Subcallosal Gyrus	R	47	18 17 -11	2.98	2.75

N = 29; All reported regions are significant at *p* < .01 for 10 contiguous voxels uncorrected.

Table 5

Correlations with attachment avodance in whole brain analysis

Region	~BA	Coordinates of peak activity	t	Z-score
Supraliminal security > supraliminal neutral contrast				
Amygdala L		-24 -10 -14	3.92	3.46
R		24 -7 17	2.80	2.60
R		24 5 -17	3.12	2.86
Cerebellum/culmen		-30 -34 -29	2.90	2.68
Insula L	13	-45 -40 22	3.57	3.20
Middle Frontal Gyrus L	6	-45 2 49	4.21	3.66
Middle Temporal Gyrus L	21	-54 -10 -17	2.98	2.74
	21	-60 -7 -11	2.95	2.72
Middle/Superior Temporal L		-54 2 -11	2.75	2.56
Parahippocampal Gyrus L	28	-18 -16 -11	4.97	4.15
Superior Temporal Gyrus L	38	-30 8 -26	3.84	3.40
L	38	-42 20 -17	3.41	3.08
L	22	-39 -55 19	3.35	3.05
L	41	-50 -22 7	3.34	3.03
R	22	66 -34 13	3.35	3.04
R	41	48 -25 4	3.31	3.01
R	42	66 -25 7	3.70	3.30

Supraliminal security > supraliminal insecurity contrast					
Amygdala	L		-27 -1 -14	3.07	2.82
Cerebellum	L		-24 -31 -35	3.44	3.11
Inferior Frontal Gyrus Orbital	R	47	21 8 -17	3.29	2.99
Parahippocampal Gyrus	L	35	-21 -19 -11	3.54	3.18
Subcallosal Gyrus	L	25	-6 14 -11	3.11	2.85
	R	25	6 14 -11	3.56	3.20
Superior Temporal	L	22	-36 -52 19	3.74	3.33

N = 29; All reported regions are significant at $p < .01$ for 10 contiguous voxels uncorrected.

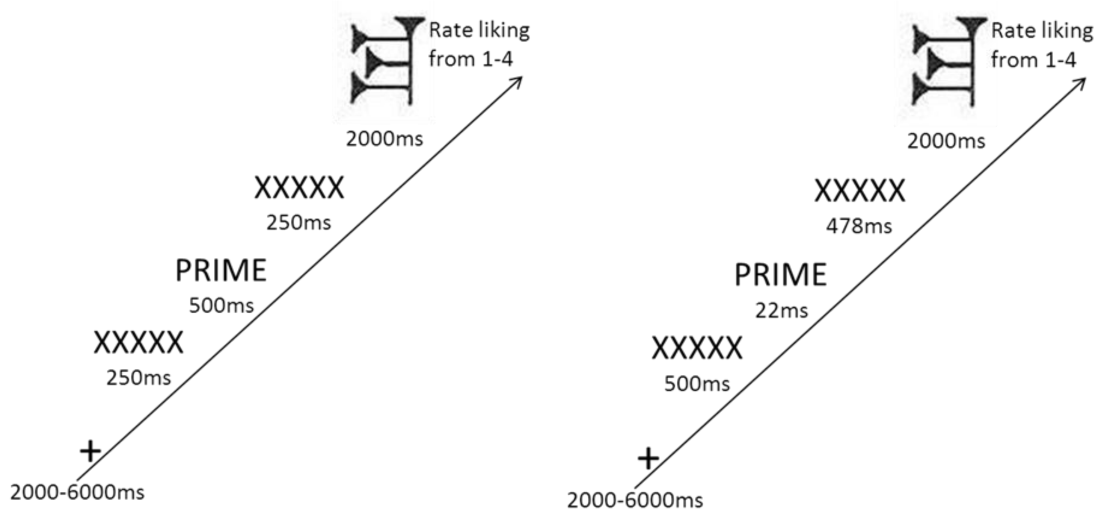

Figure 1. Depiction of the sequence of supraliminal and subliminal trials during the priming task.

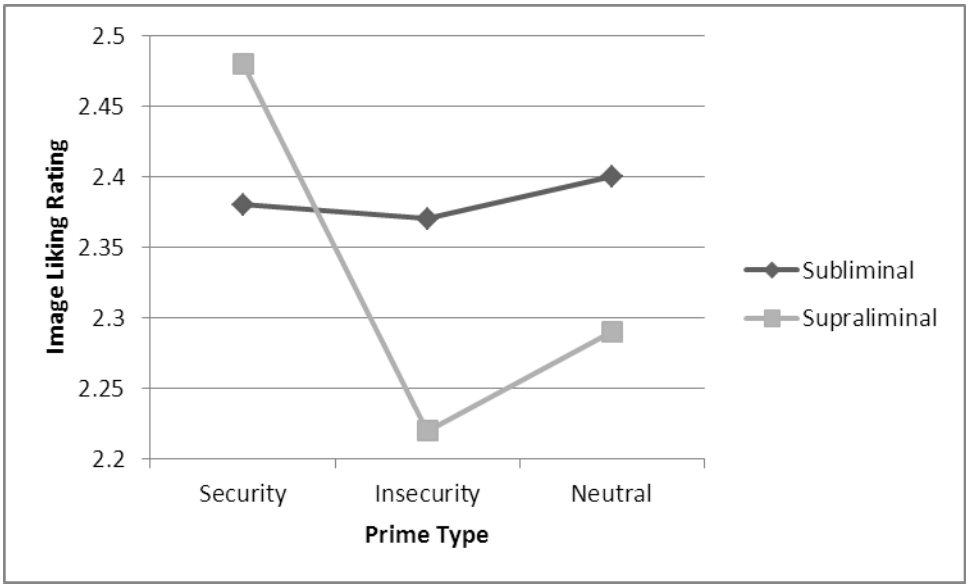

Figure 2. Plot of interaction between presentation level and prime type for liking ratings of images.

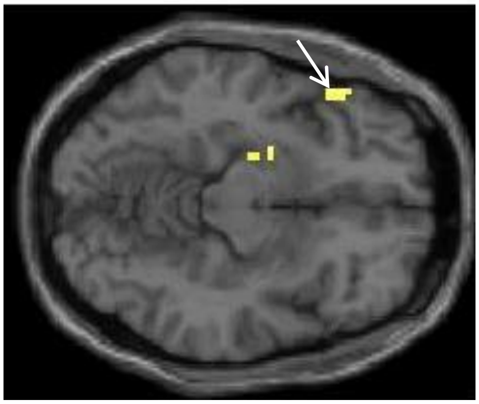

Figure 3. Peak activation in the inferior frontal gyrus (orbital, BA 47, -51 29 -11) in the supraliminal *security* > *neutral* contrast.

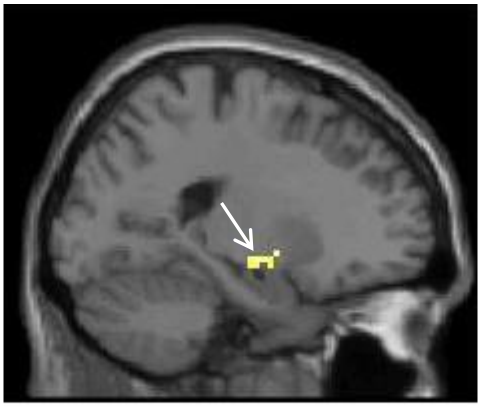

Figure 4. Peak activation in the putamen (-21 -1 -5) in the supraliminal *security* > *neutral* contrast.

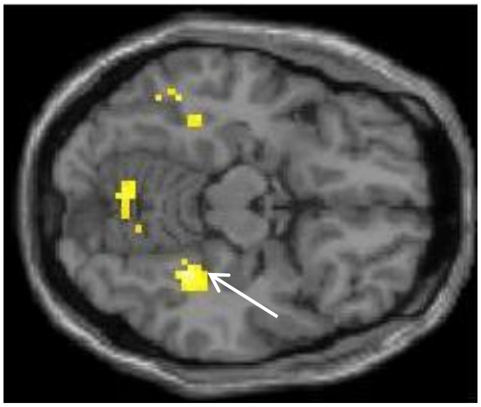

Figure 5. Peak activation in the fusiform gyrus (BA 37, 33 -43 -14) in the supraliminal *security* > *insecurity* contrast.

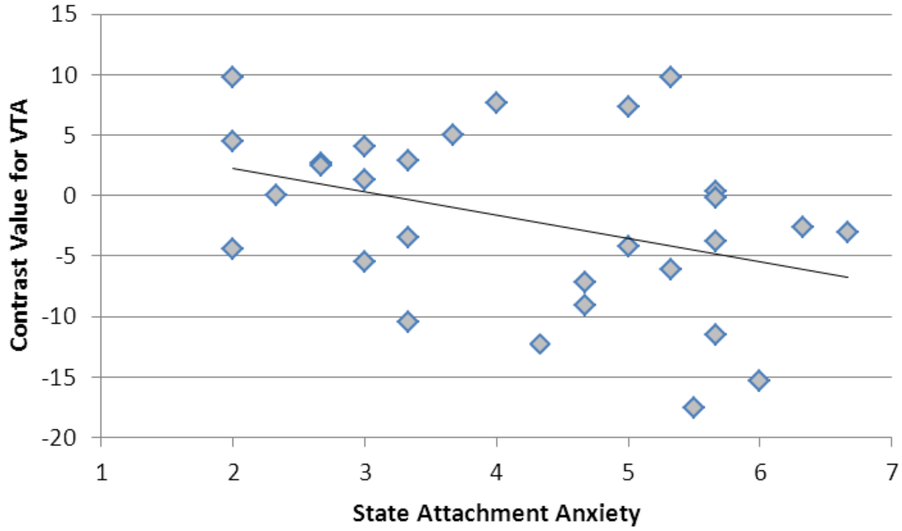

Figure 6. Correlation between state attachment anxiety and activation in the ventral tegmental area in response to the security prime compared to the fixation, $r = -.38$, $p = .04$.