Stony Brook University

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The Relationship between the Temperament Trait of Sensory Processing Sensitivity and Emotional Reactivity

A Dissertation Presented

by

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to

The Graduate School

in Partial Fulfillment of the

Requirements

for the Degree of

Doctor of Philosophy

in

Social/Health Psychology

Stony Brook University

August 2012

Stony Brook University

The Graduate School

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Abstract of the Dissertation

The Relationship between the Temperament Trait of Sensory Processing Sensitivity and Emotional Reactivity

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2012

The dissertation investigated the extent to which the temperament trait of sensory processing sensitivity (SPS) and its interaction with childhood environment, specifically parenting, predict response to emotional stimuli and its neural correlates. As SPS has been conceptualized (Aron & Aron, 1997; Aron, Aron, & Jagiellowicz, 2012), it is characterized by sensitivity to both external and internal stimuli, intense emotions, and a cognitive style characterized by a preference for elaborate processing of information. In Study 1, 101 participants (mean age 19.26; 68 females), selected from a larger pre-screened pool to represent the approximately upper and lower quartiles of SPS, viewed emotionally evocative pictures from the International Affective Picture System (IAPS), and rated their arousal to each. The key result was an interaction in which high SPS participants (compared to low), who reported positive parenting (particularly high parental care, low parental overprotection, and low parental abuse), showed more arousal to positive pictures than to neutral pictures (interaction $\beta = 0.45$, $p = 0.01$). There was no significant difference between high and low SPS, or interaction of SPS with parenting, in response to viewing negative pictures (vs. neutral pictures). In Study 2, 10 high and 10 low SPS female participants (mean age 18.68) passively viewed IAPS pictures in the fMRI scanner. Data were analyzed for activation in specific hypothesized regions of interest (ROIs), as well as in exploratory whole-brain analyses. In the ROI analysis, high (vs. low) SPS participants, after controlling for neuroticism and introversion, evidenced significantly more activation in the right putamen and globus

pallidus in response to positive (vs. neutral) pictures. The whole-brain analysis yielded greater activation for high (vs. low) SPS individuals in a fronto-temporal network in response to positive (vs. neutral) pictures. Except for coordinates in the left claustrum, and the left inferior temporal gyrus, there were no significant interactions of SPS and parenting. Overall, results suggest that individuals high in SPS are more affected than those low in SPS by emotionally positive stimuli, and that those high in SPS may be especially more affected by emotionally positive stimuli when they have had positive parenting.

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Acknowledgements

I'd like to thank my parents, Yolanta, and the late John, Jagiellowicz for modelling intellectual curiosity, valuing intellectual pursuits, and providing constant practical support. In addition, my extended family has been a model of intellectual growth and determination and I'm proud to be following in their footsteps. I especially thank my uncle Romuald and aunt Jenny for their unwavering faith and support.

Elaine and Arthur Aron, my advisors, have been mentors in every sense of the word. Likewise, I am indebted to my committee for their enduring patience, support and faith in me and their kind advice. Drs. Anne Moyer, Turhan Canli, and Nelly Alia-Klein have shared their insights and professional expertise, as well as helping me conceptualize and execute the project. I owe a great debt to the numerous Stony Brook faculty members, especially Marci Lobel, Hoi-Chung Leung, Everett Waters, and Christian Luhmann, who have taken many hours of their time to share their professional expertise. My research assistants have worked tirelessly and without complaint to advance science. I want to especially thank Kelly Yu, Kate Matyjaszek, Miriam Magana, and Rachel Han for their truly able supervision of other RAs. Gureen Singh, Eunjin Lee, Connie Yeung, Heather Kite, and Ivaylo Haydushki worked many hours, often putting my dissertation above their own work, in order to bring this project to fruition.

My friends at Stony Brook, Anna Kuhlen, Anna Floyd, Jose Colmenares, Katharina Schumann, Ceylan Cizmelli and Mert Demers have stood by me and offered social, emotional and practical support over many years. I am indebted to my friends and family in Montreal and in Cambridge, Ontario for their open doors when I needed a taste of home.

The Michael Meaney lab at McGill University in Montreal has provided intellectual stimulation and companionship while I was writing my dissertation, and for that I am grateful.

Finally, I'd like to thank my good friends Akhat Ismaguilov, who set me on the path to my PhD, and John Walsh and Mauricio Cruz, who provided a quiet workspace and moral support while I finished it.

Introduction

Sensory processing sensitivity (SPS) is an adult temperament trait characterized by high sensitivity to environmental stimuli (Aron & Aron, 1997; Aron et al., 2012). It is assessed with a standardized instrument, the Highly Sensitive Person (HSP) Scale, which has shown strong psychometric properties as well as convergent, discriminant, and construct validity. Sample items include "Are you easily overwhelmed by strong sensory input?" "Do you seem to be aware of subtleties in your environment?," "Do other people's moods affect you?," "Are you deeply moved by the arts or music?," and "Do you startle easily?" SPS is conceptually similar to traits such as introversion and behavioral inhibition. There are, however, some distinctions between the constructs. Both behavioral inhibition and SPS attribute reluctance to enter new environments to emotional reactivity. However, at least one measure of behavioral inhibition, the BIS/BAS scale Carver and White (1994) operationalizes it as emotional reactivity to negative stimuli only. This conceptualization is different from SPS, which is characterized by emotional reactivity to both positive and negative stimuli. Unlike introversion, SPS does not focus so much on the *behavior* of low sociability as it does on the underlying mechanism. This mechanism is a more thorough processing of sensory information, which causes individuals with SPS to stop and reflect prior to acting.

SPS does correlate moderately with negative affectivity/neuroticism (Aron & Aron, 1997; Aron, Aron, & Davies, 2005). However, the relationship between SPS and neuroticism appears to be found only for those individuals who report a negative childhood environment; that is, there appears to be an interaction between SPS and childhood environment such that those high in SPS are more strongly affected by their parental environment (Aron & Aron, 1997; Aron et al., 2005; Aron et al., 2012).

A number of studies have equated SPS with psychopathology, negative mental health outcomes, stress and illness (Benham, 2006; Evers, Rasche, & Schabracq, 2008; Hofmann & Bitran, 2007; Liss, Mailloux, & Erchull, 2008; Liss, Timmel, Baxley, & Killingsworth, 2005; Meyer, Ajchenbrenner, & Bowles, 2005; Meyer & Carver, 2000; Neal, Edelmann, & Glachan,

2002). Importantly, all but one of the studies used self-report, and not clinical, measures, precluding any conclusions about the clinical validity of the findings.

There is some evidence (Aron & Aron, 1997; Aron et al., 2005) that those high in SPS have stronger emotional responses overall. Individuals high in SPS were more reactive to both positive and negative emotional stimuli (Aron & Aron, 1997; Aron, Aron & Davies, 2005). Specifically, in the study by Aron and Aron (1997), childhood environment, particularly parenting, influenced the emotional reaction of individuals high in SPS. In this study, adults high in SPS, who retrospectively reported a negative childhood environment, reported more negative affectivity than high SPS adults who retrospectively reported a positive childhood environment.

A body of research suggests how neuroticism (in the negative affectivity sense) might result from a sensitive temperament paired with a non-responsive caretaker. For example, in a study of "inhibited" 9-month-olds, all of these infants reacted to novelty with an adrenergic response (Gunnar, 1994). However, only those with a non-responsive caretaker evidenced the cortisol response characteristic of chronic stress. Belsky and colleagues (1991) found that infants exhibiting negative emotionality (a sign of a sensitive temperament in infants) as 3-month-olds became less negative by 9 months of age if they had a mother whose interactions with them were complementary. Such evidence suggests that novel experiences may be perceived either as threatening or non-threatening, depending on whether a child is given the social support to deal with them.

Neural correlates of emotion perception are part of a ventral brain circuit that includes the amygdala, insula and ventral striatum (Phillips, Drevets, Rauch, & Lane, 2003a). Much of the literature (see review by Davis & Whalen, 2001) suggests that the amygdala and insula are activated in response to negative emotion. As also noted by Davis and Whalen (2001), however, dissenting studies reporting amygdala activation to positive stimuli exist as well.

The International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) is a set of standardized pictures commonly used to investigate emotional response. Individual differences in frontal, temporal and amygdala activation have been found in response to

negative, as opposed to positive, IAPS pictures for individuals high in neuroticism and for those with psychopathology characterized by negative emotionality (Canli et al., 2001; Herpertz et al., 2001). Similarly, individual differences in frontal, temporal, limbic and sub-lobar activation have been found in response to positive IAPS pictures for individuals high in extraversion (Canli et al., 2001).

The goal of this dissertation was to investigate the following questions

1. Do individuals high in SPS show a greater response to emotionally evocative stimuli than do individuals low in SPS?

2. Is any relation of SPS to response to emotionally evocative stimuli moderated by childhood environment?

3. Is there a relationship between responses to emotionally evocative stimuli and SPS independent of the relationship between responses to emotionally evocative stimuli and neuroticism and introversion?

I have investigated each of these questions both behaviorally (Study 1) and in terms of neural response (Study 2). Study 1 was a behavioral experiment to assess self-reported emotional arousal to positive, negative, and neutral pictures from the IAPS. Study 2 was an fMRI experiment to investigate neural response to these three kinds of IAPS pictures focusing on regions of interest likely to reflect individual differences in arousal in response to emotionally evocative stimuli.

Sensory Processing Sensitivity

Sensory processing sensitivity is conceptualized as a temperament trait characterized by sensitivity to both internal and external stimuli, including social and emotional cues. As noted, the standard measure of SPS in adults is the 27-item HSP Scale. Across studies, the overall measure appears to assess a single construct, as indicated by strong internal consistency, and by most factor analyses showing that the first extracted factor accounts for most of the shared variance.

The SPS concept adopts the view from biology that most species have evolved "personality" types that, although often present as a continuum, at the extremes represent two underlying strategies, variously described as shy or bold, non-aggressive or aggressive, and sensitive or not (Sih & Bell, 2008), or in the most general terms, responsive versus nonresponsive to environmental cues (Wolf, Doorn, & Weissing, 2008). One type can be summarized as "pause before acting" (Patterson & Newman, 1993) in order to allow neural processes to assess survival-related subtleties in the environment. The other is "act first" (Patterson & Newman, 1993) so as to respond quickly to opportunities and discover survival-relevant cues through motor exploration. In fruit flies, for example, there are two types, sitters and rovers, determined by a single allele and representing two strategies of locating food (Renger, Yao, Sokolowski, & Wu, 1999). In many species, these two types determine many behaviors, including feeding, harm avoidance, mating, affiliating, and seeking higher status. The two strategies persist as long as individuals with each can succeed under different but normal variations in habitat (Sih & Bell, 2008).

Sensory processing sensitivity is conceptually similar to, and shares characteristics with, some characterizations of introversion and neuroticism (Eysenck, 1963), some conceptions of the behavioral inhibition system (Gray, 1982; Gray & McNaughton, 2000a), and some conceptions of shyness (Jones, Cheek, & Briggs, 1986). These traits involve, among other things, the observable behavior of reflecting prior to acting, which has been assumed to be due variously to low sociability, low approach, low positive affect, or high anxiety.

Introversion has been associated with physiological arousal, such as sympathetic reactivity, and muscle tension in the vocal cords. Introverts (using some conceptualizations and standard measures) have also been found to have a greater awareness of subtle stimuli and more attentional vigilance (Koelega, 1992). Introversion has also been found to be associated both with reflection, defined as having a slow and accurate response style, and with a contemplative cognitive process. For example, introverts respond more slowly following a punished trial and evidence learning more from it (Patterson, Kosson, & Newman, 1987).

As part of an alternative to Eysenck's two dimensions of introversion and neuroticism, Gray and McNaughton (2000b) proposed these traits are affected by reactivity in a brain system known as the behavioral inhibition system. The behavioral inhibition system determines sensitivity to novelty, to punishment, and to non-reward, and is affected by medications that treat anxiety. Reactivity in a brain system known as the behavioral activation system determines sensitivity to stimuli associated with reward and relieving non-punishment, and is labeled "impulsivity" or impulsiveness. Gray (1983) makes an important distinction between behaviors elicited by the presence of an *actual* threat, as opposed to a *potential* threat. *Actual threat* elicits either fleeing, if the predator is far enough away, or aggressively defending oneself, if the predator is close by. Such behavior is characterized as indicating fear and occurs when an animal is moving away from, or intends to move away from, a dangerous situation. Potential threat elicits a "risk assessment" pattern, which includes inhibition of pre-predator behavior and *approach and/or scanning* of potentially dangerous stimuli or situations. Such behavior is characterized as indicating anxiety, and occurs when an animal is moving, or intends to move, *into* a potentially dangerous situation.

The "risk assessment" pattern is only necessary when there is an approach-avoidance conflict, such as a need to approach food but avoid a predator at the same time. On the surface, approach and scanning do not appear to be compatible with behavioral inhibition. There are two explanations for how such seemingly contradictory behaviors can be part of the same behavioral pattern. First, the pattern of behavior exhibited depends on the perceived risk of the potential threat. If the potential threat is high, the animal inhibits ongoing behavior (e.g., feeding) that was occurring prior to the threat (i.e., pre-predator behavior). If the potential threat is intermediate, the animal inhibits pre-predator behavior, and also initiates defensive scanning of the situation or stimuli. Once the threat is negligible, the animal decreases its approach and scanning behavior and resumes its pre-predator behavior. Second, risk assessment can be outwardly invisible because it is going on internally, involving mechanisms such as attentional shifts and memory scanning to gather information about possible threat. According to Gray and McNaughton (2000b), such internal risk assessment is definitely occurring, as evidenced by bodily changes, including greater sensitivity to startling stimuli and changes in heart rate. Both

bodily changes can be decreased with the use of anxiolytic drugs, suggesting that they are indicators of internal risk assessment and part of the "risk assessment" pattern. This is an important distinction, since, in many instances of behavioral inhibition in humans, one cannot see the external signs of the risk assessment behavior that are seen in animals, such as rearing in rats.

The "risk assessment" pattern began to be called behavioral inhibition as the result of a measurement issue. The change in "risk assessment" was measured using anxiolytic drugs. Anxiolytics both increased and decreased risk assessment measures, depending on whether a threat was actual or potential. Such a parametric relationship between risk assessment and anxiety was difficult to interpret and Gray and McNaughton (2000b) preferred to measure the "risk assessment" pattern using measures of behavioral inhibition. Viewing Gray's conceptualization of behavioral inhibition in this light equates it more easily with the "pause to check" mechanism purported to be occurring in SPS. Thus, in summary, both Gray (Gray & McNaughton, 2000b) and Aron and colleagues (Aron & Aron, 1997; Aron et al., 2005; Aron et al., 2012) propose that individuals high in behavioral inhibition/SPS inhibit pre-potent responses, assess risk, and augment arousal and recruit attentional mechanisms in response to novelty, which includes the possibility of potential reward, or potential threat. Thus, individuals with behavioral inhibition should have both strong *positive and negative* affect, not just strong negative affect.

Although earlier constructs of introversion (Eysenck, 1963, 1967) and earlier constructs of behavioral inhibition (Gray, 1982; Gray & McNaughton, 2000b) are also characterized by "pausing before acting," current or alternative interpretations of these constructs have deviated from their original meanings. Thus, a later version of Eysenck's Personality Inventory (Eysenck & Eysenck, 1975) emphasizes the sociability aspect of introversion as opposed to the impulsivity component that correlated more strongly with physiological reactivity. The correlation of SPS (Aron & Aron, 1997) with a number of measures of social introversion is substantially less than unity (even adjusting for reliabilities), typically close to $r = 0.3$, suggesting that SPS is more than just a substitute for social introversion (Aron & Aron, 1997). Also, correlations of relevant

variables (e.g., “prefer to live in the country”) with standard measures of introversion remain largely unaffected when SPS is controlled for (Aron & Aron, 1997).

Additionally, an alternative measure of behavioral inhibition, the BIS/BAS scale (Carver & White, 1994), preferentially focuses on behavioral inhibition in response to threat, whereas McNaughton and Gray (2000) postulate that arousability and behavioral inhibition is a response to all novel situations, whether threatening or not. This is the case primarily because a novel situation could potentially be a source of reward, and as such, induces an approach/avoidance conflict characteristic of the behavioral inhibition system (Gray & McNaughton, 2000b). According to Gray and McNaughton (2000b), animals will still perform a risk assessment in a novel situation, but if the situation is not potentially threatening, they will quickly return to their pre-potent behavior or even to an activation of the BAS in order to pursue reward when it is detected.

SPS typically correlates moderately with neuroticism (Aron & Aron, 1997). However, findings from studies of SPS have remained significant with minimal influence on effect size, even after controlling for neuroticism (e.g. Aron & Aron, 1997; Aron et al., 2005; Jagiellowicz et al., 2011), suggesting that it is possible to make a clear distinction between the two constructs. As with introversion, part of the controversy over whether SPS is simply neuroticism derives from changing definitions of the neuroticism construct over time. An early review of the literature (Eysenck, 1963) describes the construct as “emotionality, neuroticism, or instability as opposed to stability” characterized by “very strong emotional reactions to all classes of stimuli” (Eysenck, 1963, p. 1032). Later conceptualizations of neuroticism are based mainly on the five-factor model of personality in which neuroticism includes the facets of hostility and of subclinical anxiety and depression (John & Srivastava, 1999). These later conceptualizations of neuroticism are strongly linked with negative affect and not at all or inversely with positive affect. Emotional responses tend to be primarily negative only for those high in SPS who self-report negative childhood environments (Aron et al., 2005), suggesting it may be this sub-group of individuals that is driving the correlation between SPS and neuroticism.

Patterson and Newman (1993) describe a cognitive style of reflecting prior to acting which is characteristic of introverts. SPS shares this reflective style with some conceptions of introversion. Individuals high in SPS appear to process information more elaborately, that is, when processing stimuli they activate brain regions responsible for associating incoming stimuli with stimuli from other modalities and with information already stored in the brain (Jagiellowicz et al., 2011).

Patterson and Newman (1993) also discuss a cognitive style of acting without reflection (i.e., disinhibition), which characterizes extroverts. Disinhibition is also a characteristic of impulsiveness (Spinella, 2004) as measured by the Barratt Impulsiveness Scale-11 (Patton, Stanford, & Barratt, 1995). Since extroverts are disinhibited (Spinella, 2004), and SPS is negatively correlated with extraversion (Aron & Aron, 1997), SPS may be negatively related to impulsiveness. Impulsiveness had originally been conceptualized by Eysenck as being part of the extraversion measure of the Eysenck Personality Inventory (Eysenck & Eysenck, 1968), and later as part of psychoticism in the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975). Impulsiveness, as measured by the Barratt Impulsiveness Scale-11, (Patton et al., 1995) correlates with both the Eysenck Personality Inventory factor of extraversion and the Eysenck Personality Questionnaire factor of psychoticism.

SPS and mental health outcomes. Sensory processing sensitivity has been associated with poor mental health outcomes (Benham, 2006; Evers, Rasche, & Schabracq, 2008; Hofmann & Bitran, 2007; Liss, Mailloux, & Erchull, 2008; Liss, Timmel, Baxley, & Killingsworth, 2005; Meyer, Ajchenbrenner, & Bowles, 2005; Meyer & Carver, 2000; Neal, Edelmann, & Glachan, 2002) and higher levels of stress and ill health (Benham, 2006; Evers et al., 2008). SPS associations with poor mental health outcomes include high scores on self-reported anxiety, but not depression (Neal et al., 2002). Hofmann and colleagues (2007) investigated patients diagnosed with social anxiety disorder and found that SPS, while separate from social anxiety, was associated with harm avoidance and agoraphobic avoidance. Additionally, among two subtypes of social anxiety investigated, SPS had a stronger correlation with a generalized subtype than a non-generalized subtype. SPS was associated with features of avoidant personality disorder and borderline personality disorder in a non-clinical sample (Meyer et al.,

2005; Meyer & Carver, 2000). Individuals with borderline personality disorder features were more likely to report "rich, complex, inner lives" and be "deeply moved" by fine, subtle, and artistic experiences, whereas those with avoidant personality disorder features, were more likely to control and avoid overwhelming sensory stimulation. A second study reported an interaction between pessimism and SPS, with pessimism related to avoidant personality disorder features among highly sensitive individuals (Meyer & Carver, 2000). Liss and colleagues (2008) found relationships between factors of SPS and self-report measures of autism symptoms, alexithymia, anxiety, and depression.

The association of negative psychological outcomes for individuals high in SPS appears to be moderated by childhood environment. Individuals high in SPS appear to be more affected by environmental risk factors, such as uncaring parenting (Aron et al., 2005). Liss and colleagues (2005) also found an interaction between SPS and depression in individuals who self-reported having had low parental care.

It is important to note that all samples except for Hofmann and Bitran's (2007) were composed of either non-clinical or mixed clinical and non-clinical participants. Additionally, measures used were self-reports, not clinical interviews. Thus, although the literature suggests a tendency for higher levels of psychopathology or psychopathological features in individuals high in SPS, these results will need further investigation in clinical populations and using clinical measures, before final conclusions can be made. Indeed, the next two sections reframe "predisposition to psychopathology" as "responsiveness to the environment."

Emotional Responsiveness and SPS

Individuals high in SPS report feeling more intense emotions, both positive and negative (Aron & Aron, 1997; Aron et al., 2005). For example, in a study by Aron and Aron (1997), there was a moderate correlation between SPS and experiencing acute happiness. In another study by Aron and colleagues (Aron et al., 2005), individuals high in SPS also reported more negative affect after a negative event. The authors randomly assigned participants to complete logic tests under conditions in which either (a) the tests were very easy but the people around them were struggling (because unbeknownst to the subject, the people around them had very difficult tests)

or (b) the tests were very difficult but the people around them were proceeding easily and finishing quickly (because they had easy tests). Participants were led to believe this was a test of their applied reasoning ability. Controlling for trait negative affect, those individuals high in SPS who had completed the very difficult problems reported significantly greater state negative affect than those who had completed the easy problems (Aron et al., 2005). Although positive affect was not measured, there was a nonsignificant trend for those high in SPS who completed the easy set, and thus thought they were performing especially well on the test, to have less negative affect than those low in SPS, while those low in the trait showed essentially no reaction to how they were doing on the test performance even though a manipulation check did indicate they thought they had done poorly on a real test.

Jagiellowicz and colleagues (2012), based on results from a neuroimaging study of SPS, suggest that individuals high in SPS integrate the various neurological components of visual processing to a greater degree than those low in SPS. Presumably due to this more highly integrated processing of information, negative experiences can have a greater impact on them and can predispose them to develop chronic negative affect or neuroticism. However, positive experiences should also have a greater impact on individuals high in SPS-like traits (e.g. reactivity, biological sensitivity to context) than on those low on such traits (Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Ellis & Boyce, 2008; Ellis et al., 2005).

Personality traits correlated with SPS also affect responses to both positive and negative emotional stimuli. For example, using five-factor measures, extraversion has been linked to positive emotional response and neuroticism to negative emotional response (Clark & Watson, 1999). Additionally, individuals high in neuroticism had both poorer memory for pleasant experiences and better memory for unpleasant experiences (Mayo, 1983). Results from neuroimaging studies provide a more nuanced view of emotional response and personality constructs related to SPS. In a study of 14 women, Canli and colleagues (2001) reported that extraversion, as measured by the NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1991), was related to activation in response to viewing positive (vs. negative) IAPS pictures in a number of brain areas. These include the right amygdala and cingulate gyrus, the left middle frontal gyrus, the right inferior temporal gyrus, and the left globus pallidus, putamen and

caudate. Neuroticism was related to increased activation in the left middle temporal and left middle frontal gyri, in response to negative (vs. positive) pictures. Although neuroticism is generally thought to be related to emotional response to negative stimuli (Clark & Watson, 1999), this is not always true. In three separate studies, Britton, Ho, Taylor and Liberzon (2007) investigated the relationship between neuroticism and emotional response to IAPS pictures (Studies 1 and 2) and to emotional film clips (Study 3). They found a correlation between neuroticism and brain activation in the dorsomedial prefrontal cortex in response to positive versus neutral pictures/film clips (Britton et al., 2007). They were unable to find any significant correlations between neuroticism and response to negative versus positive pictures/film clips. However, the Britton study only analyzed brain activation in a small region of interest, the dorsomedial prefrontal cortex. It is possible that brain activation would have been found to negative stimuli had the authors investigated the entire brain.

Despite the relationships of extraversion and neuroticism with response to emotional stimuli, it is important to remember that the correlations of these personality traits with SPS are much smaller than unity (Aron & Aron, 1997). Thus, the relationship between either extraversion or neuroticism and emotional response may not always be a good proxy for the relationship between SPS and emotional response.

SPS and Childhood Environment

Aron and colleagues (Aron & Aron, 1997; Aron et al., 2005) found that negative childhood environment was related to negative affectivity in individuals high in SPS.
In this dissertation, I use childhood environment to refer to parenting plus childhood life experiences. A negative childhood environment appears to affect children high in *differential susceptibility* and *biological sensitivity to context,* both traits conceptually similar to SPS*,* to a greater degree than it does children low in SPS (see review by Kim-Cohen & Gold, 2009). However, as elaborated later in this section, *insensitive parenting*, characterized by *neglect* and *intrusiveness* (Rubin, Burgess, & Hastings, 2002, p. 25) is the aspect of a negative childhood environment that appears to have the largest impact on the development of highly sensitive children (Fox et al., 2005a; Fox et al., 2005b; Ghera, Hane, Malesa, & Fox, 2006; Hane & Fox, 2006; Henderson & Wachs, 2007). For purposes of the present research, I expected that a

measure solely of parenting would be more likely to clearly predict emotional arousal than would a combined parenting/life experience measure. Thus, insensitive parenting, operationalized as parental care and overprotection, as well as abuse, was the key aspect of childhood environment that I investigated in the present studies.

As noted, childhood environment, specifically parental neglect, intrusiveness, and abuse, has a greater impact on emotional response in individuals high in SPS than on those low in the trait (Aron & Aron, 1997; Liss et al., 2005). Thus, SPS, in combination with insensitive early parenting may result in negative responses to childhood life experiences. For example, individuals high in SPS reporting a history of poor parenting were shyer than those high in SPS with a good parental history (Aron et al., 2005); there was little difference in shyness between high and low SPS for those reporting good parenting. There is also well-established literature on the effect of parenting on the trait of behavioral inhibition in children (Fox et al., 2005a; Fox et al., 2005b; Ghera, Hane, Malesa, & Fox, 2006; Hane & Fox, 2006; Henderson & Wachs, 2007). As noted, behavioral inhibition considerably overlaps with SPS conceptually. As previously mentioned, in a study by Gunnar (1994), with 9-month old infants, behaviorally inhibited children evidenced an adrenaline response (a sign of acute stress) upon initially entering a novel situation. They also all went on to develop a chronic stress pattern of elevated cortisol levels. However, the increase in cortisol levels was mitigated by the children's attachment pattern. Behaviorally inhibited children with a secure attachment pattern, although showing approximately the same initial adrenaline response, had much less of a subsequent cortisol response than did those with insecure attachment patterns. A similar study by Nachmias (1996) found the exact same results in a sample of 18-month-old children.

Perhaps the strongest evidence for the greater impact of childhood environment on sensitive children comes from intervention studies (Belsky et al., 2007). In one study, parental skills taught to insecurely attached mothers had the most impact on "highly reactive children" and their mothers (Klein-Velderman, Bakermans-Kranenburg, Juffer, & van Ijzendoorn, 2006). Negative emotionality in infants, characterized by crying and fussing, is related to behavioral inhibition in children, and thus is conceptually similar to SPS. Infants with negative

emotionality showed up to four-fold decreases in a profile of both internalizing and externalizing symptoms at age 3 after an intervention stressing sensitive parenting (Blair, 2002).

There is some indication that individuals high in SPS or similar traits might actually have better outcomes than those low in sensitivity under low stress (Boyce et al., 1995) or positive conditions. With good parenting, sensitive or "emotionally reactive" children are healthier (Ellis, Essex, & Boyce, 2005) and "reactive" primates more likely to be troop leaders (Suomi, Brauth, Hall, & Dooling, 1991) compared to those without the trait.

Since stressful life experiences are common triggers for the development of psychopathology (Kim-Cohen & Gold, 2009), I was also interested in measuring their occurrence during the childhoods of study participants. Although childhood life experiences are important variables to assess, they promote psychopathology primarily to the extent that response to them is influenced by genetics and early parenting. In a review of gene-environment interactions, Kim-Cohen and Gold (2009) discuss how certain genetic factors promote positive adaptation, that is, "the absence of psychopathology or the presence of competence" (p. 138) despite stressful life experiences. Similarly, certain other genetic factors can predispose an individual to maladaptation to specific types of environments. For example, individuals with a short allele in the gene for the serotonin transporter, a common polymorphism in individuals high in SPS (Licht, Mortensen, & Knudsen, 2011), may be especially prone to have negative responses to childhood maltreatment.

Additionally, because life stressors, such as death of a parent or sibling, are less common than insensitive parenting, as a practical matter (i.e., in terms of available variance in the population) for purposes of the present research, I expected that a measure solely of parenting would be more likely to yield clear results than a life experience measure in predicting emotional arousal. However, since I did not want to miss identifying extreme cases, which even if uncommon could have an unusually large effect, I included a measure of life experience for exploratory purposes.

Brain Areas Involved in Emotion Processing

Phillips, Drevets, Rauch, and Lane (2003) describe emotion perception as involving three steps. The first step is appraisal and identification of the emotional significance of a stimulus. The second step is translation of the stimulus into an affective state, a process which can include autonomic, neuroendocrine and somatomotor responses, as well as the conscious feeling of an *emotion*. Since particular biases can influence the appraisal of a stimulus, the third step is automatic regulation of the autonomic response to an emotionally relevant stimulus. Brain areas activated in response to the identification and automatic regulation of emotional stimuli belong to a ventral circuit (Phillips et al., 2003). This ventral circuit includes the amygdala, insula, and ventral striatum, which are responsible for perceiving and assigning emotional relevance to a stimulus. It also includes areas responsible for the regulation of autonomic responses, such as the ventromedial prefrontal cortex (VMPFC), the orbitofrontal cortex (OFC) and the ventral anterior cingulate cortex. This ventral region of the anterior cingulate is made up of the subgenual anterior cingulate gyrus (Brodmann area 25), Brodmann area 33, and the pregenual or rostral ACC (rostral areas of Brodmann area 24).

The amygdala is a limbic structure composed of a number of nuclei and sub-nuclei. It is particularly implicated in the processing of fear and anxiety (See review by Davis & Whalen, 2001). However, there is still no consensus on whether the amygdala responds preferentially to negative stimuli relative to positive stimuli (Davidson, 2000). Bradley and Lang (2007) report that the IAPS task elicits amygdala activation to both positive and negative IAPS pictures. A review by Davis and Whalen (2001) reports inconsistencies in activation of the amygdala in response to positive pictures, with some studies finding signal increases related to the presentation of positive pictures, and some studies signal decreases.

Also according to the Davis and Whalen (2001) review, the amygdala is especially activated under conditions of uncertainty. Although based on animal studies, there is evidence that amygdala activation is greatest earliest in training, or during variable reinforcement, or when stimulus contingencies change, all of which are conditions of uncertainty. Human participants had amygdala activation in reaction to cues paired with shocks (LaBar, Gatenby, Gore, & Phelps, 1998). However, in the LaBar et al. study, they also had amygdala activation when a stimulus contingency changed. That is, there was amygdala activation at the beginning of the extinction

process, just at the point where the stimuli were no longer paired with shocks. Such findings suggest the amygdala may be implicated in the "risk assessment" or the increased arousal in response to novelty that is thought to characterize the behavioral inhibition system and SPS.

Within the ventral circuit, the anterior insular cortex combines feelings of bodily sensations with emotional information in order to arrive at a subjective moment-to-moment feeling (i.e., emotional) state (Craig, 2009). Takahashi and colleagues (2008) have reported insula activation in response to experiencing emotion. In their study, they presented participants with sentences representing joyful events. Participants imagining themselves as subjects of the joyful sentences had activation in the insula and neighboring operculum while reading the sentences. In another fMRI study (Phillips et al., 2003b), participants evidenced anterior insula activation when viewing fearful faces and/or receiving non-painful esophageal stimulation. Significantly greater activation was found when participants simultaneously experienced the esophageal stimulation and viewed the fearful faces, as compared to experiencing each condition in isolation. In addition, the level of brain activation depended on the intensity of the negative stimuli; high-intensity negative stimuli elicited more activation than medium- or mild-intensity stimuli.

The IAPS and Emotional Response

A large number of imaging studies have investigated brain activation in response to emotional stimuli. Paradigms have included emotional oddballs (Strange, Henson, Friston, & Dolan, 2000), facial expressions (L. M. Williams et al., 2001), induced mood (Shin et al., 2000) and emotional pictures from the IAPS (Lang et al., 2005), a set of pictures standardized on valence and arousal. Within these studies, the IAPS has been a particularly common means of inducing emotion. Generally, studies of neural response to IAPS pictures replicated the neural correlates included in the ventral (Banks, Eddy, Angstadt, Nathan, & Phan, 2007; Bermpohl et al., 2006; Lane et al., 1999) and dorsal (Bermpohl et al., 2006) neural networks described by Phillips et al. (2003). Temporal or occipitotemporal activation was also frequently noted in a number of studies investigating the response to IAPS pictures (Bermpohl et al., 2006; Hariri et al., 2003; Lane et al., 1999; Taylor et al., 2000)

With an occasional exception (Britton et al., 2007), individuals with psychopathologies characterized by negative emotionality/emotional lability evidence brain activation only in response to negative, as opposed to positive, IAPS pictures. Bipolar disorder was related to bilateral brain activation in the amygdala and the fusiform gyrus (BA 37), as well as brain activation in the right orbitofrontal gyrus (BA 47), and the left medial frontal gyrus (BA 10) in response to passive viewing of negative (vs. neutral) IAPS pictures (Herpertz et al., 2001). Dysthymic patients showed significantly more activity in the posterior cingulate and the fusiform gyrus in response to negative (vs. neutral) pictures, and in the amygdala and thalamus in response to negative (vs. positive) pictures (Ravindran et al., 2009). However, viewing positive (vs. neutral) IAPS pictures activated the right insula in individuals with dysthymic disorder (Ravindran et al., 2009), suggesting that both the amygdala and insula may be particularly relevant indicators of emotional arousal in general, not necessarily just to negative stimuli.

The Present Experiments and Specific Hypotheses

As spelled out above, although there have now been many studies of SPS (Aron et al., 2012), none have investigated whether SPS is related to a differentially greater responsiveness to both positive and negative emotional stimuli. The present research was designed to examine whether individuals high in SPS have greater response to emotionally evocative stimuli (both positive and negative) than those low in the trait, and whether any such differences are moderated by childhood parental environment. Specifically, I examined the following hypotheses:

Study 1 (Behavioral Study).

Hypothesis 1a. Those high in SPS, regardless of childhood environment, will report more arousal than those low in SPS in response to both positive and to negative emotional pictures (vs. neutral pictures).

Hypothesis 1b. Individuals with negative vs. positive childhood environments will report greater arousal to negative pictures (versus neutral pictures), and this difference will be greater for those high than for those low in SPS.

Hypothesis 1c. Individuals with positive versus negative childhood environments will report greater arousal to positive pictures (versus neutral pictures), and this difference will be greater for those high than for those low in SPS.

Hypothesis 1d. The effects in Hypotheses 1a through 1c will remain significant after controlling for the association of neuroticism and introversion with SPS.

Study 2 (fMRI Study).

Hypothesis 2a. Those high in SPS, relative to those low in SPS, will show more activation in brain regions known to show response to emotional stimuli (i.e., amygdala, insula, temporal cortex, occipitotemporal cortex), when shown both positive and negative emotional pictures (vs. neutral pictures).

Hypothesis 2b: Individuals with negative versus positive childhood environments will show more activation in brain regions known to show response to emotional stimuli when shown negative pictures (vs. neutral pictures), and this difference will be greater for those high than for those low in SPS).

Hypothesis 2c. Individuals with positive versus negative childhood environments will show more activation in brain regions known to show response to emotional stimuli, when shown positive pictures (vs. neutral pictures), and this difference will be greater for those high than for those low in SPS.

Hypothesis 2d. The effects in Hypotheses 2a will still be significant even after controlling for the association of neuroticism and introversion with SPS.

Distributional issues. I selected two subsets for further study (i.e., high SPS and low SPS). Kagan (1994) characterized what I am calling "sensitive" individuals as comprising between 20 and 25 percent of a population. Based on my previous research, the desired subgroup scoring within the "lump" of the focal temperament trait (high SPS) comprise about 20% of the usual samples in the Stony Brook psychology subject pool.

General Method

Sample selection and screening

Figure 1 is a schematic of the screening and selection process for Studies 1 and 2. Students at Stony Brook University were recruited by means of the following methods: mass testing of introductory psychology course students, psychology department subject pool, class recruitment, on-campus flyers, and recruitment in the academic mall (stopping passers-by). Women over 45 were not recruited, since, historically, their scores on ratings of the IAPS pictures differ from women younger than 45 years (Bradley & Lang, 2007). Participants gave informed consent. All procedures were approved by the Institutional Review Board at Stony Brook University. All 1200 recruited participants completed the following scales: HSP Scale, childhood environment measures, and short introversion (I) and neuroticism (N) scales. Of the 1200 participants recruited, 511 were screened (i.e., were asked the questions in Appendix B to determine eligibility for the study), and 156 were selected for follow-up, with 116 of these selected for Study 1, the behavioral experiment. The number screened is substantially less than the number recruited because only those subjects falling into the high and low SPS categories were screened. Additionally, the initial 300 mass testing participants recruited in the spring 2009 were not contacted until late in the fall semester 2009/early in the winter semester 2010. By that time, most of the respondents were not on campus and were unwilling to be screened for an experiment. By the spring 2010 semester, many of the participants were no longer in classes requiring research credits. For Study 2, the fMRI study, I selected participants with scores at the extreme top and bottom of the SPS scale (after eliminating the top and bottom most extreme 2.5% of scorers) until I arrived at 33 female participants.

Participant selection for follow-up

Participants were pre-screened from the pool of 1200 students (744 females). I took the top and bottom 20% (after excluding 2.5% from each of the top and bottom) of the original fall 2009 distribution and assigned a range of SPS scores to both high and low SPS conditions in each experiment. As participants became harder to enroll, I increased the percentage of the distribution recruited from 20% to 35%, and hence, extended the range of scores within the high

and low SPS categories. Participants became harder to recruit because many of the low SPS scorers did not pass the eligibility criteria with respect to freedom from alcohol, tobacco, and drug addictions or psychopathologies. Table 1 lists the category scores used to screen participants for the fMRI and behavioral studies for each semester.

Using 20% as an estimate, to have 76 participants high in SPS; I needed to screen 360 participants. I initially estimated I would need to add additional participants since I wanted to exclude the very extreme scorers on SPS. I excluded 2.5% of those at both extremes, that is, those with scores more than approximately two standard deviations from the mean. Since SPS is correlated with sub-clinical anxiety and depression, such extreme scorers could perhaps have been within the range of scores for clinical anxiety and depression. They also might have represented cases that were simply answering all items at the top or bottom end of the scale without paying attention to their meaning. It is also possible that those scoring extremely low on the SPS scale were characterized by clinical impulsiveness. To allow me to exclude these extreme scorers, who comprised 5 % of the total, I estimated I would need a screening sample size of 375. Due to the actual method of selecting participants for follow-up screening, described in Study 1, as well as late follow-up of the original screened sample (Spring, 2009), the initial sample of 375 did not yield enough enrolled subjects. Thus, additional samples were screened starting in Fall 2009 and ending in Spring 2011 until 1,200 participants were enrolled. Only about 12% of participants that were screened for the low SPS category actually participated in the final experiment. This is mainly because, as noted briefly above, many of the lowest scorers on SPS did not pass the eligibility criteria for the study. Study participants needed to be free from substantial tobacco or drug use or psychopathologies.

Measures of variables assessed at recruitment.

With respect to childhood environment, I used measures of both parenting and childhood life experiences, since, as noted earlier, both variables have been shown to have an impact on psychological outcomes later in life (Kim-Cohen & Gold, 2009). However, as also mentioned earlier, I considered life experience as less important a predictor of psychological outcomes than I did parenting. Thus childhood life experience was assessed as an exploratory variable. In order

to separate the effects of introversion and neuroticism from the effect of SPS on the dependent variables, I included brief items which have been shown to correlate with more lengthy and widely used measures of neuroticism and introversion in a past study of SPS (Aron & Aron, 1997)

Participants completed the following well-established psychometrically strong (as elaborated below) measures: (a) Highly Sensitive Person Scale (HSP Scale; Aron & Aron, 1997), the standard measure of SPS, (b) Parental Bonding Instrument (PBI; Parker, Tupling, & Brown, 1979), (c) Measure of Parenting Style-Abuse Subscale (MOPS; Parker et al., 1997), (d) The Positive and Negative Affectivity Scale (PANAS; Watson, Clark, & Tellegen, 1988), (e) a set of relatively objective items measuring childhood environment from Aron and Aron (1997), (f) four items measuring neuroticism and introversion used in previous studies of SPS (Aron & Aron, 1997), and (g) the Life Experience Questionnaire (Canli et al., 2006). I also included demographic information and an open-ended question previously used in the Arons' studies (A. Aron, personal communication, January 2009) to screen for participants not taking the testing seriously.

The HSP Scale is a 27-item measure described earlier (including example items). It discriminates SPS from social introversion. HSP Scale scores correlate .31 with a social introversion measure operationalized as a composite of the Eysenck Personality Inventory (Eysenck & Eysenck, 1968) and the Big Five Extraversion/Surgency. The HSP Scale is more closely related to neuroticism (*r*s ranged from .45 to .58 over a series of studies by (Aron & Aron, 1997). Cronbach's alphas for the HSP Scale in previous studies have ranged from .85 to .87 (Aron et al., 2005; Benham, 2006). In my sample, Cronbach's alpha was .90. Correlations with other measures are described below in the Results section for Study 1.

The PBI (Parker et al., 1979) is a retrospective self-report measure of the parental contribution to the parent-child bond, commonly used in studies of parental rearing styles (Parker, Barrett, & Hickie, 1992). For example, Rhodes and Kroger (1992) investigated the relationship of perceived parental bonding characteristics to eating disorders. They reported higher levels of maternal overprotection in late adolescent women suffering from eating

disorders. Daire (2002) reported that sons giving care to a parent with dementia reported less distress associated with the caregiving role if they had received more care from their parents as a child.

There are two PBI versions, a mother form, and a father form. Respondents completed both versions. Each version of the scale consists of 25 items with 12 loading on a "care" factor and 13 loading on an "overprotection" factor. Example care items are "spoke to me in a warm and friendly voice" and "did not help me as much as needed", example overprotection items are "let me decide things for myself" and "was overprotective of me." Responses are on a Likert scaling 0 "very like" to 3 "very unlike." The maximum score on the "care" subscale is 36, and on the "overprotection" subscale is 39. The PBI items have high internal consistency (Parker et al., 1992) and validity. Cronbach's alphas in my sample were .72 and .65 for the overall mother and father scales, respectively, and .94 and .92 and .88 and .90 for the mother and father care and overprotection subscales, respectively.

The maternal and paternal versions of the MOPS-Abuse Subscale (Parker et al., 1997) are used to measure maternal and paternal abuse. The MOPS-Abuse Subscale includes items about parental indifference, physical and sexual abuse, and loss. These factors increase the risk for later anxiety or depression in children. Since sub-clinical anxiety and depression (neuroticism) are correlated with SPS, the MOPS-Abuse Subscale (maternal and paternal versions) seemed like a good complement to the PBI in this study.

The MOPS-Abuse Subscale includes refined PBI items capturing mechanisms relating parental neglect and intrusiveness to psychiatric disorders. It also includes parental abuse and separation subscales. Since SPS is considered a normal personality trait, and not a psychiatric disorder, and since I was not studying a clinical sample, I did not use the refined PBI items relating to psychiatric disorders. However, since I was interested in the interaction with SPS of all aspects of childhood environment, including abuse, I did include the abuse subscale from the MOPS in my measures. According to Parker and colleagues, the MOPS-Abuse Subscale is sufficiently independent of the PBI to suggest it might provide additional information in applied studies. The MOPS abuse subscales have good convergent validity (Parker et al., 1997). There

are five items on each of the MOPS father abuse and mother abuse subscales. Responses are rated on a 4-point Likert scale, from 0 to 3. Respondents judge how well the items describe how their mother and their father, independently, treated them during their first 16 years. Responses are "not true at all," "slightly true," "moderately true," and "extremely true." Cronbach's alphas in previous studies were .87 and .92 for maternal and paternal abuse, respectively (Parker et al., 1997). Reliability was high in my sample as well, with alphas of .86 and .87, respectively.

Children who are abused and neglected are at greater risk of developing health and emotional problems. However, as noted earlier, I consider parental bonding, as opposed to child abuse, as the key childhood environment measure because it is more sensitive to the normal range of negative childhood environments. Although child abuse is a common operationalization of negative childhood (Parker et al., 1997), I argue that it is *insensitive parenting* and not abuse that is the key variable. Abusive parents are, by definition, insensitive to their child's needs. Thus insensitive parenting is a more comprehensive measure of negative childhood (which includes abuse), than strictly an abuse scale.

Insensitive parenting has been primarily measured by observing parent-child interactions. As previously mentioned, it is a key predictor of sensitive (i.e., "behaviorally inhibited") children developing future psychopathologies, such as social withdrawal, relationship difficulties and internalizing symptoms such as anxiety. The PBI, besides being the standard questionnaire used in retrospective studies of parenting, is an ideal self-report measure of such behavioral interactions because it assesses the same parental behaviors that are assessed by observations of parents with their behaviorally inhibited children (Booth-LaForce & Oxford, 2008; Fox et al., 2005a; Fox et al., 2005b; Ghera et al., 2006; Hane & Fox, 2006; Henderson & Wachs, 2007) . Parker and colleagues (Parker et al., 1979) reviewed these behavioral studies and operationalized neglect and intrusiveness as the care and overprotection subscales of the PBI.

The Positive and Negative Affectivity Scale (Watson et al., 1988) is a commonly used scale to measure both positive and negative affect. Positive affect (PA) is the extent to which a person feels enthusiastic, active, and alert and it constitutes a state of pleasurable engagement. Low PA corresponds to sadness and lethargy. Negative Affect (NA) includes anger, contempt,

disgust, fear, and nervousness and constitutes a state of unpleasurable engagement. Low NA corresponds to a state of calmness and serenity. The PANAS consists of 10 feeling words describing PA and 10 feeling words describing NA. Sample items include "interested," "upset," "irritable," and "enthusiastic. Participants rate the words on a Likert scale from 1 to 5, corresponding to how likely they are to feel the emotion described by the word. Higher values correspond to greater NA and greater PA. Although originally conceptualized as state dimensions, NA and PA are also related to the traits of negative emotionality and positive emotionality, respectively. Thus, PANAS items can be worded to gather information on the participant's feelings, in general, which was done in the present studies. The PANAS has good convergent and discriminant validity and Cronbach's alphas range from .86 to .90 for PA and from .84 to .87 for NA. The alphas in my sample were .89 for PA and .90 for NA. In the present study, I included the PANAS as a possible covariate in the various tests of my hypotheses.

The neuroticism, introversion, and short "Aron Parenting Scale" items used in this study were used in the original studies of SPS (Aron & Aron, 1997) as well as various subsequent studies (Aron et al., 2005). The Aron parenting scale consists of eight items. Sample items included, "Were you close to your father? "Were you close to your mother?" "Would you characterize your childhood as troubled?" "Were you prone to hide as a child (under beds or tables, in closets, bushes, etc.)?" (the last two items are reverse scored). In the present study, alpha was .74. Neuroticism was assessed with the two items "Are you prone to depression?" and "Are you prone to fears?" Alpha for a 3-item measure in a previous study (PANAS; Watson et al., 1988) was .75, and, for the two-item measure used here, was .71. Social introversion was assessed with the two items "Do you prefer to spend time with one or two close friends rather than a large circle of friends? and "Do you like to meet strangers?" Aron et al. (2005) found this two-item social introversion scale correlated highly with standard measures of social introversion. Alpha for this 2-item measure in a previous study (Aron & Aron, 1997) was .70 and in this study was .40, indicating low reliability of this measure. Items are answered on a 7-point Likert scale, with 1 indicating "not at all" and 7 indicating "extremely."

I modified a version of the Canli Life Experience Questionnaire (Canli et al., 2006) which itself used items developed in a life history calendar (Caspi et al., 1996). The modified

Life Experience Questionnaire I used was composed of items related to death and serious illness, family and relationships, physical and sexual assault, and other stressful life events (see Appendix A). Sample items include "Death of a family member," "Parents separated," Serious problems in relationships with friends," and "Any other stressful event (car crash, house fire, earthquake, military combat). Please specify." Participants were asked to check yes or no to indicate whether or not any of the events happened to them in their first 16 years of life, and if so, to indicate the approximate year of the event or their age at the time. Reliability and validity data have not yet been gathered (T. Canli, personal communication, March, 2009). The original measure was, however, used to measure life stress in a study of epigenetic vulnerability to depression (Caspi et al., 1996).

Childhood environment scores were calculated from an aggregate of scores on all parenting/childhood environment self-report measures (the four PBI subscales, the two MOPS versions, and the Aron Parenting scale). The weighting of each measure was based on a factor analysis of the seven scales in the entire sample. That is, based on a factor analysis of the set of 7 parenting scales, I used each subject's factor score from the first unrotated principal component as my primary measure of parental environment. Factor loadings are given in Table 2. Childhood environment was treated as a continuous variable in the statistical analysis.

Materials

The IAPS (Lang et al., 2005) is a standardized set of over 1000 pictures (see Figure 2 for an example) rated on their valence and arousal. It is a widely used task (a Web of Science literature search of the term yielded 138 results in investigations of emotion and attention). The IAPS pictures have been previously rated by a large group of people for the feelings of arousal and pleasure they elicit. Pictures are catalogued on the basis of the average mean and standard deviation of the affective ratings. Ratings of the IAPS have good convergent validity (Lang et al., 2005).

I selected pictures from the *International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual* (Lang et al., 2005). These pictures had the following ranges of standardized mean arousal values rated on a 9-point scale: positive pictures ranged

from 4.17 to 6.73; neutral pictures from 2.23 to 5.46 and negative pictures from 4.45 to 5.89 in arousal value. Valence values, also rated on a 9-point scale, were as follows: positive, 6.43 to 7.77, neutral, 3.72 to 6.17, and negative, 2.49 to 4.69. I used pictures from the center of the range of arousal scores. Since high SPS individuals are easily overwhelmed by strong stimuli, I wanted to avoid any possible ceiling effect linked to the presentation of IAPS pictures at the high end of the arousal continuum.

The Self-Assessment Manikin (SAM; Bradley & Lang, 2007) is a well-validated self-rating instrument (Lang, 1980). It consists of two sets of five graphic figures, used to acquire ratings of arousal and pleasure for IAPS pictures. The bottom set represents arousal and the top set represents valence. The participant fills in any of the five figures, or the box between the figures, resulting in a 9-point scale for arousal and a 9-point scale for valence (see Figure 3).

Study 1: Behavioral Study

Study 1 was designed to test hypotheses about the extent to which SPS and its interaction with parenting predict reported arousal to emotional stimuli, as well as to provide the opportunity to conduct exploratory analyses of the extent to which SPS and its interaction with parenting predict response times to, and valence ratings of, emotional stimuli.

Method

Participants. The 101 participants included in the analyses included 68 women and had a mean age of 19.26 years. Table 3 presents means and standard deviations of age and SPS score for the participants whose data were analyzed.

Research design and procedure. Study 1 used a between-participants design with SPS status (high or low) and childhood environment (measured as a continuous variable) as the independent variable. Childhood environment was operationalized as comprising both parenting and life experience. Parenting, operationalized as parental neglect, intrusiveness and abuse, as well as a composite measure of the previous three components, plus others discussed in the Materials section, were investigated in the main analyses. Life experience was investigated in an exploratory analysis. The focal dependent variable was self-reported arousal following each

picture. Specifically, I assessed response to positive and negative pictures. I also assessed neutral pictures in order to provide a baseline control condition. The valence ratings of, and response times to, the IAPS pictures were obtained for an exploratory analysis.

Participants passively viewed 24 negative, 24 neutral, and 24 positive pictures selected from the IAPS picture set. As previously mentioned, pictures were selected from the middle of the arousal and valence ranges, in order to control for a possible ceiling effect in individuals high in SPS. Pictures were presented following protocols modified from Canli and colleagues (2001) and Ribeiro, Teixeira-Silva, Pompeia, and Bueno (2007). There were 75 trials, 18 blocks of four pictures each of the same type (positive, negative, or neutral), plus 3 practice trials at the beginning of the entire sequence of trials. Participants viewed blocks of pictures of the same type rather than interspersing positive, negative, and neutral pictures in order to ensure sufficient time for emotional response to build for each type of picture. Each picture was presented for 6,000 ms. For the initial two blocks, participants were given 10 seconds, as per Ribeiro and colleagues (2007), immediately after viewing each picture to rate it first on valence, then on arousal, using the SAM. For subsequent blocks, participants were given 8 seconds to rate valence and then arousal. The initial block (after the practice trials) seen by a participant was composed of neutral pictures. Starting with the second block, the following blocks of pictures were counterbalanced across participants. Specifically, one participant saw a "positive trial in which the second block of pictures was composed of positive pictures, and the next participant saw a "negative trial" in which the second block of pictures was composed of negative pictures.

Main Results

Statistical analyses. To establish whether Study 1 supported the previous literature on emotional reactivity to IAPs pictures, I conducted paired-sample t-tests for positive versus neutral IAPS pictures and for negative versus neutral IAPS pictures for the overall sample for each arousal condition.

To test the hypotheses, I conducted three regression analyses in each of which the main predictors, entered hierarchically, were high-low SPS (as a dummy-coded dichotomous variable), parenting (the weighted sum of the 7 parenting scales using their first unrotated factor,

continuous), and their product (to test the interaction). The three regression analyses were the same except for different dependent variables. The dependent variables were arousal scores to positive pictures and arousal scores to negative pictures. All regression models also included the arousal response to the neutral stimuli as a unique predictor (entered before all other predictors). Partialing out the neutral stimuli, as opposed to subtracting it, accounts more accurately for its overlap with the DVs of interest. I also conducted the three regression analyses using the afore-mentioned predictors, except that the general measure of childhood environment was replaced, in the main analysis, with parenting as measured by the PBI mother and father forms (mother and father PBI scores are generally reported separately in the literature) and, in the exploratory analysis, with life experience, measured by the Canli Life Experience Questionnaire.

To test the prediction of a main effect of childhood environment, as listed in Hypotheses 1b and 1c, I conducted a regression analysis in which the main predictor was childhood environment. As previously mentioned, for purposes of the main analysis, I defined childhood environment as parenting. Thus, I conducted regressions using the following parenting scales: the weighted sum of the 7 parenting scales using their first unrotated factor, and the PBI mother and father forms (mother and father PBI scores are generally reported separately in the literature).

I conducted two additional regression analyses, one for arousal to positive pictures and one for arousal to negative pictures, in each of which the predictor (along with arousal to neutral pictures) was the SPS residual (high/low SPS after partialing out neuroticism and introversion).

Response times (RTs) were not analyzed for arousal. Since the SAM figures for recording valence were always presented prior to the SAM figures for recording arousal, participants may have anticipated the arousal figures, which could have affected RTs for arousal. However, in addition to the analyses described above which tested my hypotheses, I was able to carry out a series of exploratory analyses focusing on valence RTs and valence ratings in response to IAPS pictures. Unlike the situation for arousal, it was possible to conduct analyses of RTs for valence because they were presented prior to the arousal ratings, thus they were the first rating done in response to each picture.

Overall results. Participants were more aroused by emotional than by neutral pictures. Their arousal scores were significantly different to negative than to neutral pictures $t(95) = 11.48$, $p < .001$, 95% *CI* [1.5, 2.2] and to positive than to neutral pictures, $t(95) = 13.01$, $p < .001$, 95% *CI* [1.5, 2.0]. Arousal scores to negative pictures ($M = 5.04$, $SD = 1.90$) were similar to those for positive pictures ($M = 5.00$, $SD = 1.55$). Likewise, participants gave significantly different valence scores to emotional pictures as versus neutral pictures. The difference between scores given to negative, versus neutral, pictures was significant $t(87) = -24.86$, $p < .001$, as was the difference between the scores given to positive, versus neutral, pictures $t(90) = 19.98$, $p < .001$. As expected based on norms (Bradley & Lang, 2007), negative and positive pictures were ranked respectively lower and higher on the SAM scale, than were neutral pictures. Response times were longer to negatively valenced pictures than they were to positively valenced pictures or neutral pictures, showing that participants looked longer at negative pictures than positive or neutral pictures. See Appendix D for overall means (and *SDs*) for arousal, valence RT, and valence scores in response to positive, negative, and neutral pictures.

Results for tests of hypotheses.

Hypothesis 1a. *Those high in SPS, regardless of childhood environment, will report more arousal than those low in SPS in response to both positive and negative emotional pictures (vs. neutral pictures)*. In testing this hypothesis, the dependent variable was mean reported arousal to both positive and negative pictures, controlling for mean reported arousal to neutral pictures for each. SPS status did not significantly predict greater arousal to either positive or negative pictures.

Hypothesis 1b. *Individuals with negative versus positive childhood environments will report greater arousal to negative pictures (versus neutral pictures), and this difference will be greater for those high than for those low in SPS.* The dependent variable was mean reported arousal to negative pictures controlling for mean reported arousal to neutral pictures. Childhood environment, specifically, parenting, did not predict arousal to negative IAPS pictures. Regressions of the 7-scale weighted parenting variable, and each of the PBI Father and Mother care and overprotection scales on arousal scores to negative (controlling for neutral) pictures, all

yielded nonsignificant results (See Appendix E). Neither did any of the SPS status X Childhood environment interactions significantly predict arousal to negative pictures (see Appendix C). Also none of the interaction effects for the Life Experience measure were significant for this analysis.

Hypothesis 1c. *Individuals with positive versus negative childhood environments will report greater arousal to positive pictures (versus neutral pictures), and this difference will be greater for those high than for those low in SPS*. The dependent variable was mean reported arousal to positive pictures controlling for reported arousal to neutral pictures.

Parenting on its own did not predict arousal to positive IAPS pictures. Specifically, regressions of arousal scores to positive (controlling for neutral) pictures, on the 7-scale weighted parenting variable, and each of the PBI Father and Mother care and overprotection scales, all yielded nonsignificant results (See Appendix E).

The Life Experience scale did not significantly contribute to arousal to positive pictures. However, the interaction of SPS status with each of four of the childhood environment variables (weighted 7-scale parenting variable, PBI mother overprotection, PBI father care, and PBI father overprotection) did contribute significantly to positive arousal ratings (See Table 4). Simple effects were mostly in the direction expected (see Table 5). That is, for individuals high in SPS, to a significantly greater extent than those low in SPS, the better the parenting, the larger the arousal response to positive pictures. Indeed, the simple effect for those high in SPS was significantly positive for PBI father overprotection and PBI father care, and with a trend towards significance for weighted 7-scale parenting (See Figures 4-6). The simple effect for those in the high SPS status group was not significant for mother overprotection. For those low in SPS, it was significantly negative.

Hypothesis 1d. *The effects in Hypothesis 1a through 1c will still be significant even after controlling for the association of neuroticism and introversion with SPS*. To test this, I summed each of the two neuroticism and the two introversion items to give a total neuroticism score and a total introversion score. I then constructed a residual score for SPS controlling for these two variables (i.e., the residual SPS as predicted from the neuroticism and introversion). This SPS

residual did not significantly predict arousal scores to positive pictures or arousal scores to negative pictures (in each case controlling for arousal to neutral pictures).

Exploratory Results

I conducted parallel exploratory analyses to those of the main results, controlling for neutral stimuli, with valence RT and valence ratings as the DVs. Additionally, I controlled for and tested interactions of SPS status with impulsiveness, positive affectivity, negative affectivity and gender.

Neither SPS status, nor SPS residual, significantly predicted valence ratings of positive pictures. SPS residual had a trend towards significance in predicting the response time (RT) it took to rate negative pictures on the valence dimension ($\beta = -.13$, $p = .06$). The higher the SPS residual score, the less time it took to respond to negative pictures.

With respect to the interaction between SPS status and the childhood environment variables, most of the interactions made no significant contribution to any measures other than the arousal scores, as described in the Hypothesis Test section. The exception was the weighted 7-scale parenting variable**.** The interaction of the weighted 7-scale parenting variable and SPS status had a trend towards significance for positive valence response ratings (See Table 6). Regression testing (see Table 5) revealed simple effects of the weighted 7-scale parenting variable at different levels of SPS status. In individuals high in SPS, high scores on the weighted 7-scale parenting measure (i.e., positive parenting) trended towards significance in predicting higher valence scores in response to positive pictures. The relationship between valence responses to positive pictures and high scores on the weighted 7-scale parenting measure was nonsignificant in those low in SPS. As seen in Appendix C, the interaction of Life Experience with SPS status also made no significant contributions to any other valence measures (i.e., positive\negative valence RTs, positive\negative valence responses).

Additionally, SPS status residual did not significantly predict valence RT or valence scores to either positive or negative pictures.

The correlation matrix of SPS status, impulsiveness, positive and negative affectivity, and gender yielded significant correlations only between SPS status and gender and SPS status and PA/NA. However, a series of further analyses examining the effects of including these variables indicated that in no case did they affect the significance, or significantly moderate any, of the results reported above. The results were uncorrected for multiple comparisons, since they were already nonsignificant when uncorrected. If the above results were unaffected even with uncorrected *p* values, then they would have been even less affected (i.e., less significant) once corrected for multiple comparisons.

Discussion

Overall, as expected based on the literature, participants responded to the picture manipulations according to the IAPS norms (Bradley & Lang, 2007). Specifically, positive pictures and negative pictures elicited higher arousal scores and higher and lower valence scores, respectively, than did neutral pictures.

With respect to the impact of SPS on arousal, Hypotheses 1a and 1d were not supported. Neither SPS status alone, nor SPS status controlling for neuroticism and introversion, predicted positive or negative emotional arousal. Further, Hypotheses 1b was not supported—there were no significant main effects of parenting or interactions of parenting with SPS status in predicting response to negative pictures. Finally, there was no support for the first aspect of Hypothesis 1c—there were no significant main effects of any parenting variable on response to positive pictures.

However, as predicted in the interaction aspect of Hypothesis 1c, SPS clearly interacted with childhood environment to predict arousal to, as well as valence ratings of, positive pictures. As noted in Table 4, a positive childhood environment predicted greater arousal to positive pictures in sensitive participants and lower arousal in non-sensitive participants. There was also a significant SPS X childhood interaction in predicting valence scores to positive pictures, such that for those high in SPS the better the childhood, the more positive the valence rating for positive pictures; but for those low in SPS there was no significant association of these ratings with childhood environment. These findings are consistent with a key aspect of the majority of

findings in the current literature. That is, individuals high in SPS and similar traits benefit more from a supportive environment than do non-sensitive individuals (Aron et al., 2012; Belsky & Pluess, 2009; Ellis & Boyce, 2008). The striking lack of main effects of SPS (or SPS residual), for any main effects of parenting, or for interaction of SPS with parenting for negative pictures is considered in the General Discussion.

Study 2: fMRI Study

Method

Participants. This was an fMRI study with 20 female participants (9 high, 11 low in SPS). I originally scanned 33 participants, but had to exclude the data from 13 due to a number of factors outlined in Figure 1, including experimental error, corrupt data, and a brain anomaly. Participants were selected during pre-screening to be the most extreme in their cells (excluding as noted earlier those in the very top or bottom 2.5%). I used only females to minimize variance due to gender differences in response to the IAPS task (Blair, 2002; Klein Velderman, Bakermans-Kranenburg, Juffer, & van Ijzendoorn, 2006). Also, because the Stony Brook subject pool had many more women than men, it would have been difficult to create equal numbers of high and low SPS for each gender that did not differ on other variables. Table 7 presents means and standard deviations of age and SPS score for the fMRI participants whose data were analyzed.

Sample selection and screening. As explained in the General Method section of this dissertation, 2.5% of the most extreme scoring participants from each end of the distribution were disqualified. Of the remaining participants who met the basic pre-screening criteria, the participants with the most extreme scores in each cell (high and low SPS status) were contacted and pre-screened for fMRI suitability (see Appendix B for an example of a pre-screening script) until 33 participants were recruited (approximately 8 from each cell). Additional exclusion criteria for the fMRI experiment included metal in the body, current psychopathology, left-handedness, severe alcohol or drug use, and expected claustrophobia in the fMRI environment. There was also a specific question about whether the participant would be willing to be in an fMRI experiment.

Research design and procedure. The research consisted of three phases: (a) general pre-screening, as in the General Methods section, (b) pre-screening for fMRI, and (c) the scanning session itself. Study 2 used the same general design as Study 1 but instead of reported arousal and valence response to the IAPS pictures, the focal dependent variable was neural

activation in regions known to be responsive to emotional stimuli. I also conducted an exploratory analysis of neural activation in the whole brain in response to emotional stimuli.

Study 2 consisted of the IAPS task described in the General Methods modified for the fMRI scanner as described below. The task took approximately 8 minutes in the scanner. Participants passively viewed the IAPS pictures in the scanner. There were 75 trials, presented in 18 blocks of four pictures each (with the four pictures in each block being of the same valence), with 3 practice trials at the beginning of the entire sequence of trials. As in Study 1, participants viewed blocks of pictures of the same valence rather than interspersing positive, negative, and neutral, in order to ensure sufficient time for emotional response to build for each type of picture. Each picture was presented for 6,000 ms with an interstimulus interval (i.e., fixation cross) of 1,125 ms. The initial block (after the practice trials) seen by a participant was composed of neutral pictures. As in Study 1, starting with the second block, the subsequent blocks of pictures were counterbalanced across participants. Specifically, one participant saw a "positive trial" in which the second block of pictures was composed of positive pictures, and the next participant saw a "negative trial" in which the second block of pictures was composed of negative pictures.

After having completed all IAPS tasks, participants completed the Post-Scanning Questionnaire. The Post-Scanning Questionnaire asked participants to indicate their level of anxiety while in the scanner on a Likert scale from 1 to 7, with 1 representing "not at all" and 7 representing "extremely." Mean reported anxiety in the scanner was 2.62 on a scale of 7. Since the sample was comprised of women only, they also reported how many days it had been since their last menstrual period. This was done so that I could consider stage of the menstrual cycle as a potential covariate.

Scanning. I acquired functional pictures on a 3T Siemens MAGNETOM TrioTim magnetic resonance imaging scanner (Siemens Ag, Washington, DC., USA) at the SCAN Center, Stony Brook University, and recorded blood oxygen level-dependent responses. I acquired functional pictures using T2-weighted gradient-echo echo-planar sequence (repetition time 2,000 ms, echo time 30 ms, 80˚ flip angle, field of view 240 X 240 mm, 64 X 64 matrix).

The pictures consisted of 30 contiguous axial slices of mm thickness, with no gap between slices. Voxel size was 3.8 X 3.8 X 4.0 mm. Three volumes were introduced before beginning the set of blocks for the experiment and were discarded from analysis. Excluding the discarded volumes, 257 volumes were acquired during the 8:34 min functional scan. I also acquired anatomical, axial T1-weighted scans (repetition time 300 ms, echo time ms, 256 X 256 matrix, 80˚ flip angle, 240 mm X 240 mm field of view, slice thickness 4 mm) in the same session. Voxel size for the anatomical scans was 0.9 X 0.9 X 4 mm.

Visual stimuli (IAPS pictures and fixation crosses) were projected on a screen placed directly outside the MRI tube, subtending a visual angle of 178˚. Participants viewed pictures via an angled mirror mounted on the RF coil of the scanner. Pictures were shown using a personal computer running Eprime software (Version 2.0, Psychology Software Tools, Pittsburgh, PA).

Main Results

Statistical analysis. I identified five ROIs based on the literature as reviewed in the introduction, specifically from fMRI studies of effects of IAPS pictures on emotion perception. Central coordinates for each ROI and the study it is from are shown in Table 8. For each ROI, I identified a 10 mm sphere based on the central coordinate from the study the ROI is based on, and conducted a series of tests, following standard procedures, in which I used a small volume correction of .05 (FDR; minimum cluster size = 10).

First, I conducted overall group-level ROI analyses for my two key contrasts (i.e., positive vs. neutral and negative minus neutral) and their opposites (i.e., neutral minus positive and neutral minus negative).

Next, I conducted a series of tests of my Study 2 hypotheses, consisting of a total of twelve regressions for each ROI. Six regressions were tests for my two key contrasts (positive vs. neutral and negative minus neutral), each carried out for each of the three hypothesized predictor variables: SPS status (for Hypothesis 2a), SPS status residual (i.e., after partialing out N and I; for Hypothesis 2d), and SPS status X parenting residual (i.e., the product term of SPS

status X parenting, after partialing out the main effects of SPS status and parenting; for Hypotheses 2a and 2b). Additionally, I tested the opposite contrasts (i.e., neutral minus positive and neutral minus negative) for each of the regressions.

Finally, I also conducted exploratory between-group whole-brain analyses for each of my major regressions (on each of the four contrasts), using uncorrected $p < 001$, voxel threshold = 25. . I also conducted correlations between SPS status and reported anxiety participants felt when in the scanner, as well as between SPS status and days since last menses. Since there were no significant correlations, I did not include either of the preceding variables as covariates in any of the regression analyses.

Assuming a medium ($r = .3$) effect size, a post-hoc power analysis with an FDR alpha of .05, and a total sample size of 20 for regressions using the covariate SPS status alone yielded a power level of .39 (one-tailed). However, based on my advisor's experience with power analysis, and since the fMRI sample participants were extreme scorers, I also calculated power based on a continuous sample. Including middle values for SPS, power was .75 (one-tailed). Thus, actual post-hoc power assuming a medium effect size would lie somewhere between .39 and .75.

Overall group ROI results. ROI analyses at the overall group level yielded activation primarily for the contrast negative minus neutral. Negative pictures elicited significantly greater brain activations than did neutral pictures in each of the right amygdala and the bilateral middle temporal gyrus (see Table 9). There were no significant activations in the tested ROIs for the positive versus neutral, the neutral minus negative, or the neutral minus positive contrasts. Whole-brain analyses yielded stronger significant brain activations for the positive versus neutral contrast, with activations in the left hemisphere; specifically the left cuneus, the left middle occipital gyrus, the bilateral lingual gyri, and the left fusiform (see Table 10). There were also significant activations for the negative versus neutral contrast. Activations were found in the right middle temporal gyrus, the right precuneus, and the bilateral fusiform gyri. There were also limbic activations, specifically in the left parahippocampal gyrus, the right posterior cingulate and the left uncus. All lobes of the brain, except the cerebellum, were activated for the contrast

neutral versus negative (see Appendix F). Frontal, temporal and parietal areas were likewise activated for the neutral versus positive activation contrast.

Results for tests of hypotheses.

Hypothesis 2a. Those high in SPS, relative to those low in SPS, will show more activation in brain regions known to show response to emotional stimuli (i.e., amygdala, insula, temporal cortex, occipitotemporal cortex), when shown both positive and negative emotional pictures (vs. neutral pictures). When conducting this analysis, the dependent variable was brain activation in response to the contrasts positive versus neutral pictures and negative versus neutral pictures. SPS status did not significantly predict greater brain activation in any of the *a priori* ROIs.

Hypothesis 2b: Individuals with negative versus positive childhood environments will show more activation in brain regions known to show response to emotional stimuli when shown negative pictures (vs. neutral pictures), and this difference will be greater for those high than for those low in SPS). When conducting this analysis, the dependent variable was brain activation in response to the contrast of negative minus neutral pictures. The interaction between SPS status and childhood environment did not significantly predict greater brain activation to negative, versus neutral, pictures in any of the *a priori* ROIs.

Hypothesis 2c. Individuals with positive versus negative childhood environments will show more activation in brain regions known to show response to emotional stimuli, when shown positive pictures (vs. neutral pictures), and this difference will be greater for those high than for those low in SPS. When conducting this analysis, the dependent variable was brain activation in response to the contrast of positive minus neutral pictures. The interaction of SPS status and childhood environment did not significantly predict brain activation to positive, versus neutral, pictures, in any of the *a priori* ROIs.

Hypothesis 2d. The effects in Hypotheses 2a through 2c will still be significant even after controlling for the association of neuroticism and introversion with SPS. When conducting this analysis, the dependent variable was brain activation in response to the contrasts positive versus

neutral pictures and negative minus neutral pictures. As shown in Table 11, I found significant activation for the positive versus neutral contrast in an ROI centered on the right amygdala coordinates of 25 -5 -26. The contrast positive versus neutral regressed on sensory processing sensitivity residual (i.e., SPS controlling for N and I) yielded activation in the right putamen and the right globus pallidus (see Figure 7). There were no significant activations in any *a priori* ROIs for the negative versus neutral contrast**.**

Exploratory Results

Between-group whole-brain results. Table 12 shows significant regional activations for each of the regressions tested in the whole- brain analysis. The main findings were significant activation, predicted by SPS status (controlling for neuroticism and introversion), for the positive versus neutral contrast in a fronto-temporal network, in limbic areas, and in the cerebellum. The fronto-temporal network consisted of the left middle temporal gyrus (see Figure 8), the left inferior temporal gyrus, and the left fusiform gyrus in the temporal lobe; and the left superior, middle and inferior gyri in the frontal lobe. Limbic area activation was present in the left parahippocampal gyrus, the left claustrum, the bilateral putamen, the left globus palidus, the right caudate, the left cingulate gyrus, and in the left anterior nucleus of the thalamus. Activation other than in the fronto-temporal network and the limbic areas was found in the posterior lobe.

There was activation in the right declive, as well as in the left claustrum and left inferior temporal gyrus for the negative versus neutral contrast predicted by SPS status and by SPS X Parenting, respectively.

The neutral versus negative contrast, as predicted by SPS status, yielded significant activation in the bilateral middle frontal gyrus and the right inferior parietal lobule (see Table 13).

Discussion

Overall group results are similar to those found in reviews of the literature, with brain activation primarily in response to negative emotional stimuli. My overall group ROI analyses yielded activation in the amygdala in response to viewing negative versus neutral IAPs pictures.

Reviews by both Bradley and Lang (2007) and Davis and Whalen (2001) suggest that the amygdala is activated by negative emotion. Overall ROI and whole-brain results for this contrast include middle temporal lobe activation, as also reported by Domes and colleagues (2010). As supported by a previous study (Bermpohl et al., 2006), I also found occipitotemporal (i.e., fusiform gyrus) activation in response to negative, as opposed to neutral IAPs pictures.

My hypothesis of greater activation for those high (vs. low) in SPS of specific emotional ROIs (i.e., amygdala, insula, temporal cortex, occipitotemporal cortex) in response to both positive and negative emotional pictures was not supported. However, ROI analyses of a sphere centered on the right amygdala yielded greater activation in the right ventral putamen and the right globus pallidus in response to positive stimuli. Additionally, whole-brain analysis yielded numerous coordinates related to brain regions specialized for processing incoming visual stimuli, appraising incoming stimuli, producing affect and emotional behavior, and automatically regulating autonomic function.

Regarding the hypothesized ROI results found for greater positive response in those high in SPS in the putamen and globus pallidus, both of these regions are part of the basal ganglia, a brain area which links cognitive and limbic domains with motor domains (Bradley & Lang, 2007; Davis & Whalen, 2001). Regions of the basal ganglia (i.e., the putamen and caudate nucleus) receive projections from the amygdala, as well as cortical and thalamic input, and send them to the globus pallidus, which processes them and sends them to motor and non-motor areas (Goldberg & Bergman, 2011). The fact that the putamen receives projections from the amygdala suggests that the amygdala was possibly activated in response to positive stimuli, but the study lacked the power to show significant activation.

A number of pieces of evidence suggest that the putamen and globus pallidus areas yielded by my ROI analysis are associated with channelling visual information. First, the ventral putamen receives output from the inferior temporal visual cortex (Goldberg & Bergman, 2011; Middleton & Strick, 2000). Second, animal research has located specific neurons in the ventral putamen that fire in response to visual cues (Caan, Errett, & Rolls, 1984). Additionally, the globus pallidus has efferents that project back to non-motor areas of cortex, creating an

anatomical loop (G. V. Williams, Rolls, Leonard, & Stern, 1993). One such cortical target is the inferotemporal cortex. My whole-brain analysis yielded a large, significant cluster of activation in the inferotemporal cortex in response to positive versus neutral stimuli in individuals high in SPS (see Table 12). Such findings suggest that the activation I noted in both the ROI and whole-brain analyses may correspond to a visual processing circuit that is more activated in individuals high in SPS.

As mentioned in the section of this dissertation entitled Brain Areas Involved in Emotion Processing, Phillips et al. (2003) describe emotion perception as involving three steps. The first step is appraisal and identification of the emotional significance of a stimulus. The second step is production of affective states and emotional behaviors, and the third step is automatic regulation of the autonomic response to an emotionally relevant stimulus. Neither SPS alone, nor SPS interacting with parenting, predicted significant brain activation in any emotional regions outlined in my hypotheses. However, using an exploratory whole-brain analysis, SPS, after controlling for neuroticism and introversion, predicted significant activation primarily in response to positive stimuli in brain areas related to processing incoming visual stimuli, appraising the emotional significance of stimuli, and production of an affective state and regulation of autonomic responses. There was one coordinate in the left inferior temporal gyrus, an area related to processing incoming visual stimuli, that was activated in response to negative stimuli. The strong relationship between high SPS and the above-mentioned brain areas found in response to positive pictures suggests that SPS is related to appraising incoming emotional stimuli as more positive, producing greater positive affect, and requiring greater effort to regulate autonomic responses to the positive stimuli.

Activation in the left inferior temporal gyrus, an area of association cortex responsible for the representation of visual objects (Rolls, 2007), suggests that this area was activated in response to viewing the pictures. According to Rolls, the amygdala appraises the emotional significance of a stimulus, and one route by which the incoming visual stimuli gets to the amygdala is through the inferior temporal lobe.

The amygdala then sends outputs to the striatum (i.e., putamen and globus pallidus), then through the thalamus to the premotor cortex to generate implicit behavioral responses (Rolls, 2007). I found multiple loci of activation in the putamen and globus pallidus and adjoining thalamus, with centers of local maxima spatially clustered within an area of approximately 20 mm in diameter. Functionally, the basal ganglia assign reward value to incoming stimuli (see review by Schultz, Tremblay, & Hollerman, 1998). In a meta-analysis, Phan, Wager, Taylor, and Liberzon (2002) reported that nearly 70% of the happiness induction studies they analyzed found basal ganglia activation. Basal ganglia activation was thus reasonable in the present study, given that many of the positively valenced IAPS pictures were of intrinsically pleasurable food.

Whole-brain analysis also yielded activation in the ventral region of the left anterior cingulate cortex (i.e., the rostral part of Brodmann area 24). This activation was part of a larger cluster centered on the right caudate. According to a review by Phillips et al. (2003), Brodmann area 24 is associated with autonomic function and emotional behavior. An anatomical study, (Ghashghaei & Barbas, 2002) investigated the connections of amygdala inputs and outputs in the monkey. The authors reported amygdala connections to a number of prefrontal areas, including the anterior cingulate gyrus, suggesting these links allowed the amygdala to provide information about the emotional relevance of stimuli to prefrontal areas such as the anterior cingulate.

In summary, the above arguments suggest a role for SPS, controlling for introversion and neuroticism, in enhancing the identification of stimuli due to more elaborate visual processing, in increasing the appraisal of the stimuli due to increased anterior cingulate activation, and in enhancing the behavioral response to pleasurable stimuli due to more basal ganglia activation. These arguments will be developed more fully, with respect to visual processing, in the General Discussion.

In my analyses focusing on individual differences in SPS, there was greater brain activation for the positive versus neutral than for the negative versus neutral conditions. These results are in contrast to those of other studies investigating individual differences in emotional response to IAPS pictures. For example, Herpertz et al. (2001) reported that individuals with bipolar disorder, relative to healthy individuals, had greater amygdala activation to passive

viewing of negative versus neutral IAPS pictures. However, she did not include positive pictures, precluding any conclusions about brain activation to positive pictures. Ravindran et al. (2009) found significantly more activation in individuals with dysthymia, compared with healthy controls, in response to both passive viewing of negative and of positive, versus neutral, IAPS pictures.

Coordinates reported in my whole-brain analysis were very similar to coordinates found by Canli et al. (2001) corresponding to a correlation of extraversion with response to positive (vs. negative) IAPS pictures (see Table 14). Specifically, both extraversion and SPS (controlling for neuroticism and introversion), predicted response to positive IAPS pictures in the left putamen, the left lateral globus pallidus, and the left middle frontal lobe. The difference between any two x, y or z coordinates ranged from 3 mm for the x coordinates to 15 mm for the z coordinates. Although the coordinates in my study were generated by an uncorrected whole-brain analysis, I used a $p < .001$ cutoff and a 25-voxel threshold to provide some control for multiple comparisons. The coordinates were also found in clusters that were quite large. The left putamen and left globus pallidus coordinates were part of the same cluster of 117 voxels, whereas the frontal lobe coordinates were both part of a cluster of 105 voxels. The fact that the coordinates were so similar for four out of the 15 coordinates given in the Canli et al. study lends them even more credibility.

Findings that both extraversion and SPS (controlling for neuroticism and introversion) activate similar brain regions in response to positive IAPS pictures suggest that SPS *per se* does not lead to a negative emotional bias. The negative bias appears to be connected to neuroticism or introversion, since, once these are controlled for, individuals high in SPS are just as likely to respond positively to positive IAPS pictures, as are extraverts. Also, these individuals did not necessarily have to come from a positive parental environment, since the brain activation to positive pictures was not predicted by an interaction between SPS and parenting.

Importantly, the participants in the studies mentioned above (Herpertz et al., 2001; Lane et al., 1999; Ravindran et al., 2009), were either neurotic or had some type of psychopathology. As discussed in more detail in the General Discussion section of this dissertation, both Studies 1

and 2 of this dissertation excluded participants with psychopathologies. Additionally, in Study 2, the majority of significant brain activations to positive pictures were obtained when neuroticism and introversion were partialled out of SPS. Since both neuroticism and psychopathology are associated with negative affect (Costa & McCrae, 1992), presuming there is not some unique contribution of SPS residual to negative stimuli, it is reasonable that I found significant brain activation primarily to positive pictures.

General Discussion

The prediction that individuals high in SPS would be more affected than those low in SPS by emotional stimuli was not supported in the behavioral experiment (Study 1), but was partially supported in the fMRI experiment (Study 2). Specifically, an exploratory whole-brain analysis revealed that SPS, controlling for neuroticism and introversion, significantly predicted brain activation to positive versus neutral pictures in limbic areas, and in the temporal lobe and frontal lobe areas.

Interestingly, SPS status did not predict emotional arousal on its own. However, when other traits, such as neuroticism, that might also predict emotionality to stimuli, were controlled for, SPS did predict emotional arousal. Since neuroticism involves a tendency towards negativity, it is reasonable that it may have undermined the tendency towards positivity. Thus the tendency towards positivity showed up once neuroticism was controlled for in high SPS individuals. Indeed, in several analyses in the original study of the SPS measure (Aron & Aron, 1997) several key results were clearer only when neuroticism was controlled.

Results of both studies were much stronger and clearer for positive than for negative pictures, both for SPS controlling for neuroticism and introversion and for the SPS by childhood environment interaction. This contrasts with a large body of literature (Carver & White, 1994; Kagan, 1994; see also section in this dissertation entitled SPS and Mental Health), concerning negativity and sensitivity and related variables. However, the pattern observed in the present studies is more in keeping with the newer "differential susceptibility to environment" hypothesis (Belsky & Pluess, 2009; Boyce & Ellis, 2005). Indeed, Boyce et al. (1995) have found both highly positive and highly negative outcomes on a health outcome (i.e., respiratory illness) depending on childhood environment.

It is entirely possible that SPS, defined as a trait within the normal range of personality, is characterized more by emotionality in response to positive stimuli, then emotionality in response to negative stimuli. I found significant response to positive stimuli and almost exclusively to positive stimuli in two different studies using two different DVs. Additionally, one of the DVs, brain activation, is what is known as an endophenotype (Canli et al., 2006). An endophenotype

is a dependent variable that is closer to the physiological and biological underpinnings of a personality trait and thus more sensitive than clinical assessment or self-reports. However, a recent paper suggests that traits are more predictive of future behavior than is brain function (Nees et al., 2012).

In several key analyses, individuals high in SPS were more affected by their childhood environment than were those low in SPS. In Study 1, those high in SPS who reported a positive childhood environment had more positive arousal than did participants low in SPS who also reported a positive childhood environment. Indeed, an overall combined weighted measure of several scales, as well as two of the most important individual scales within it (i.e., father overprotection and father care), each significantly predicted greater arousal to positive pictures in those high in SPS.

SPS status, either interacting with childhood environment, or controlling for introversion and neuroticism, also predicted, respectively, valence scores given to positive pictures and RTs to negative pictures. Individuals high in SPS responded more quickly to negative pictures than did individuals low in SPS. This result is in contrast with findings of slower RTs associated with high SPS (Jagiellowicz et al., 2011). However, the Jagiellowicz et al. study investigated processing of non-emotional pictures which do not necessarily elicit fast responses. There is evidence that emotional stimuli are attended to more than non-emotional stimuli (Anderson & Phelps, 2001) suggesting that response to emotional stimuli could be faster than to non-emotional stimuli.

Some of the literature showing a connection between SPS and negative emotionality has included the entire spectrum of scorers on the HSP Scale, possibly confounding SPS with clinical anxiety and depression. Since neuroticism, characterized by sub-clinical anxiety and depression, is correlated with SPS, it makes sense that individuals at the high end of the SPS continuum could possibly have clinical symptoms of anxiety and depression. In that case, it would be logical that individuals high in SPS would also be more affected by negative stimuli than those low in SPS. Liss and colleagues (2005) reported that an interaction between SPS and low PBI-care predicted depression in individuals high in SPS. However, Liss et al. did not

screen out individuals with psychopathologies. Liss and colleagues report a mean SPS score of 5.03 for their high SPS condition, as compared to 4.83 for the same condition in my Study 1 (behavioral study) sample. Since SPS is considered a normal personality trait, and not a psychiatric disorder, it seems valuable to restrict samples to individuals without known psychopathologies. My sample excluded individuals falling more than 2 SDs from my sample mean on the HSP scale (i.e., the top and bottom 2.5% of scorers on the HSP scale) in order to control for individuals with possible clinical anxiety and depression. Additionally, I screened out any participants with current or past psychopathologies or taking psychoactive medication. Seeing as my sample excluded psychopathologies, it may have also excluded individuals with the extreme negative childhood environments that could have predicted those psychopathologies. Those participants remaining in the sample may not have evidenced arousal to negative stimuli because they didn't have a sufficiently negative childhood environment to interact with their SPS. This would seem to be a valuable area for further investigation.

Interestingly, a number of areas of activation in the current studies of SPS were similar to those found in a previous fMRI study of SPS and higher order visual processing (Jagiellowicz et al., 2011). Specifically, there were a number of coordinates in this study in the right declive (i.e., 30 -76 -30, 22 -78 -26) that, at their furthest point, were within 10 mm to 18 mm of the coordinates 28 -60 -30 found in my previous fMRI study (Jagiellowicz et al., 2011). A very interesting line of research suggests that the cerebellum is not only involved in locomotion and motor activities, but forms "neural loops" with other brain areas (Middleton & Strick, 2000). These include the basal ganglia and the frontal lobe, both areas in which I found brain activation in the present Study 2. Another cerebellar "loop" area, in which I found activation, was the inferotemporal cortex, a region involved in visual recognition and discrimination. Other brain areas activated both in this dissertation and the Jagiellowicz et al. (2011) study were part of a network associated with controlling eye gaze, paying attention to stimuli, and integrating multimodal stimuli with other information in the brain. Since emotion enhances the perception of stimuli that have motivational significance (Anderson & Phelps, 2001), the activation of an enhanced visual attention and processing network in those high in SPS suggests this more elaborate visual processing (including visual attention) network is a possible mechanism through

which SPS and emotionality could be related. In the present studies, behavioral findings of faster RT to emotional pictures for those high in SPS, as well as the neural coordinates listed above, suggest this processing network may be more active in those high in SPS either as a resting state network, or as a network which subsumes any type of visual processing. Further investigation would be worthwhile.

Strengths and Limitations

This set of studies was unique in its size and its attempt to recruit individuals at the extremes of the normal range of SPS. To the best of my knowledge, there is no other study investigating SPS which is drawing from the endpoints of such a large pool of recruited participants. However there were a number of limitations in my study. Perhaps a reason I failed to find activation in more of the ROIs in the fMRI study, was the nature of the samples. Indeed, even after recruiting approximately 1200 individuals and screening 500 of them, I was able to recruit so few individuals into the fMRI studies at the lower end of the SPS score continuum that I was enrolling individuals scoring within the behavioral study scoring range into the fMRI experiment. These individuals may not have been sufficiently low in SPS to yield the magnitude of activation differences in the contrasts that I had predicted.

Also, the fMRI study may have been underpowered. The ROIs are by definition, small areas. As discussed earlier, my sample had a power value somewhere between .39 and .75. A power value above .80 is generally considered an appropriate minimally adequate level of power. Thus, there is a chance that Study 2 did not have enough power to detect a significant effect of the magnitude predicted.

In addition, as mentioned in the General Methods section, the IAPS task used pictures from the center of the range of arousal scores. Since high SPS individuals are easily overwhelmed by strong stimuli, I wanted to avoid any possible ceiling effect linked to the presentation of IAPS pictures at the high end of the arousal continuum. However, the pictures I used may not have been high enough in arousal to generate significant differences in emotional arousal between low and high SPS groups.

Finally, the nature of the sample suggests that results should be generalized with caution to populations geographically different from that of the study. The study was conducted in the suburbs of a large U.S. metropolis. The area has a commuter culture, characterized by noise, haste, and traffic congestion. The environment seems not conducive to individuals high in SPS, who are easily overstimulated. (Aron & Aron, 1997; Aron et al., 2012). This may have led to a selection bias in the population of the region, which would militate against recruiting individuals scoring in the higher ranges of SPS. And, of course, more generally, one must be cautious in generalizing from a North American college sample to other social class or cultural contexts.

Conclusion

The results of these studies are important for a number of reasons. They provide unique support for the idea that SPS is associated with positive, and not just negative, emotions. They add to the evidence (Aron & Aron, 1997; Aron et al., 2012; Jagiellowicz et al., 2011) that SPS is distinct from neuroticism and introversion. They also add support to the evidence that there is an interaction between sensitivity and parental environment in which those who are highly sensitive are more influenced by their parenting.

In a broader sense, the results support Aron's (2010) argument that SPS is not itself a clinical condition. High SPS individuals who encounter positive events appear to be more affected for the good than those low in SPS. In sum, the present studies provide the first direct test of the relation of SPS to response to emotional stimuli. Results of both behavioral and neural measures suggest that SPS may be associated particularly with response to positive stimuli, and that this greater responsiveness of those high in SPS may be particularly strong for those with good parenting.

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Appendices

Table 1

Highly Sensitive Person (HSP) Scale Score Ranges for Recruited Participants by Category and Semester

Experiment	SPS Group	Fall 2009	Spring 2010	Fall 2010
Behavioral	high	4.5 to 5.0	4.5 to 5.0	4.5 to 5.0
Behavioral	low	3.0 to 3.4	3.0 to 3.4	3.3 to 3.8
fMRI	high	5.1 to 5.6	5.1 to 5.8	5.1 to 5. 8
fMRI	low	2.4 to 2.9	1.6 to 2.9	2.6 to 3.2

Note. SPS = Sensory Processing Sensitivity, fMRI = functional magnetic resonance imaging.

Table 2

Factor Loadings for First Unrotated Factor of Childhood Environment Measure in Weighted 7-Scale Parenting Measure

Factor	Loading
PBI Father-Overprotection	.301
PBI Mother-Overprotection	.286
PBI Father-Care	-.307
PBI Mother-Care	-.265
Aron Scale Parenting Items	.223
Measure of Parental Style (MOPS)–Mother	.122
Measure of Parental Style (MOPS)–Father	.094

Note. Scoring on individual scales: high scores on PBI Care indicate a negative childhood; high scores on PBI overprotection and MOPS indicate a positive childhood. PBI = Parental Bonding Instrument.

Table 3

Study 1 Means and Standard Deviations of Low and High Sensory Processing Sensitivity (SPS) Groups on Highly Sensitive Person (HSP) Scale Score and Age

	HSP score			Age		
	N	Mean	SD	N	Mean	SD
Low SPS	44	3.29	.38	36	19.36	1.87
High SPS	57	4.83	.28	49	19.18	1.20

Table 4

Study 1 Hierarchical Multiple Regression Analyses Predicting Positive Arousal Response Rating from Sensory Processing Sensitivity (SPS) Status, Parenting, and SPS Status by Parenting Interaction

Model	Step	Predictor	Beta[a]
Analysis with 7-Scale Parenting			
	Step 1	Neutral Arousal Response Rating	.54**
	Step 2	SPS status	.06
	Step 3	Weighted 7-Scale Parenting	.00
	Step 4	SPS status X weighted 7-Scale Parenting	.45***
Analysis with PBI-Mother overprotection			
	Step 1	Neutral Arousal Response Rating	.54***
	Step 2	SPS status	.06
	Step 3	PBI-Mother Overprotection	-.01
	Step 4	SPS status X PBI-Mother Overprotection	.55*
Analysis with PBI-Father care			
	Step 1	Neutral Arousal Response Rating	.58***
	Step 2	SPS status	.01
	Step 3	PBI-Father Care	-.08
	Step 4	SPS status X PBI-Father Care	-.67*
Analysis with PBI-Father overprotection			
	Step 1	Neutral Arousal Response Rating	.58***
	Step 2	SPS status	.01
	Step 3	PBI Father-Overprotection	.04
	Step 4	SPS status X PBI-Father Overprotection	.86**

Note. Neutral arousal response rating entered first as a control. Higher scores on the overall weighted 7-Scale Parenting sum indicate positive childhood experience. Scoring on individual scales: high scores on PBI Care indicate a negative childhood; high scores on PBI overprotection and MOPS indicate a positive childhood. PBI = Parental Bonding Instrument.
[a]Standarized regression coefficient for this variable at the step when it is first added to the equation.
p< .05,p<.01**, p <.001****

Table 5

Study 1 Simple Effect Regressions of Childhood Environment Variables on International Affective Picture System (IAPS) Dependent Variables by Sensory Processing Sensitivity (SPS) Status for Analyses in which the Interaction was Significant

Regressor	Dependent Variable	N	Beta	*p*
Weighted 7-Scale Parenting				
High SPS	Pos Arousal Response	52	.22	.07
Low SPS	Pos Arousal Response	39	-.41	.001
High SPS	Pos Valence Response	52	.26	.06
Low SPS	Pos Valence Response	39	-.15	.41
PBI Mother-Overprotection				
High SPS	Pos Arousal Response	56	.12	.32
Low SPS	Pos Arousal Response	40	-.27	.04
PBI Father-Care				
High SPS	Pos Arousal Response	56	-.28	.02
Low SPS	Pos Arousal Response	40	.26	.03
PBI Father -Overprotection				
High SPS	Pos Arousal Response	56	.27	.03
Low SPS	Pos Arousal Response	40	-.37	.004

Note. Neutral arousal response rating entered first as a control. Higher scores on the overall weighted 7-Scale Parenting sum indicate positive childhood experience. Scoring on individual scales: high scores on PBI Care indicate a negative childhood; high scores on PBI overprotection and MOPS indicate a positive childhood. PBI = Parental Bonding Instrument.

Table 6

Study 1 Hierarchical Regression of Sensory Processing Sensitivity (SPS) Status, Parenting, and SPS Status by Parenting Interaction on Positive Valence Rating

Step	**Predictor**	**Beta**	***p***
1	Neutral Arousal Response Rating	.06	.56
2	SPS status	.10	.33
3	Weighted 7-Scale Parenting	-.14	.42
4	SPS status X Weighted 7-Scale Parenting interaction	.33	.06

Note. High scores on Weighted 7-Scale Parenting signify good parenting.

Table 7

Study 2 Means and Standard Deviations of Low and High Sensory Processing Sensitivity (SPS) Groups on Highly Sensitive Person (HSP) Scale Score and Age

		HSP score		Age	
	N	Mean	SD	Mean	SD
Low SPS	11	3.50	0.24	19.00	0.82
High SPS	9	4.72	0.29	18.33	0.50

Table 8

Study 2 Coordinates Used in Region of Interest (ROI) Analyses

Region	MNI Coordinate x, y, z	Analyses/Contrasts Used in Source	Source
L Insula	-27 18 12	emotional intensity one-sample t-test	Phan et al., 2004
R Amygdala	25 -5 -26	pos > neg pictures	Canli et al., 2001
L Amygdala[a]	-22 -6 -11	various contrasts	Costafreda, 2008
R Amygdala[a]	21 -6 -11	various contrasts	Costafreda, 2008
R middle temporal gyrus	51 -63 0	negative > neutral pictures	Domes et al., 2010
L middle temporal gyrus	-54 -69 6	negative > neutral pictures	Domes et al., 2010

Note. R=right, L=left. MNI = Montreal Neurological Institute.
[a]Meta-analysis. 96% of 179 activation foci from the meta-analysis were between the left amygdala and the right amygdala coordinates listed.

Table 9

Study 2 Coordinates for Significant Activation in Regions of Interest (ROIs) for Negative versus Neutral Contrast for Overall Group

ROI	Location	Size (k)	MNI Coordinates x, y, z	Z
Neg > Neutr				
25 -5 -26	R amygdala	27	22 -4 20	3.21
21 -6 -11	R Amygdala	11	20 -6 -20	3.67
51 -63 0	R middle temporal gyrus	247	50 -72 4	4.49
			42 -64 -6	3.27
-54 -69 6	L middle temporal gyrus	286	-50 -76 4	4.20
			-54 -72 10	3.85
			-48 66 12	3.75

Note. ROIs are defined as a 10 mm radius sphere around the coordinates given. FDR=.05, k>10. R = right. L = left. MNI = Montreal Neurological Institute.

Table 10

Study 2 Coordinates of Significant Whole-Brain Activations at the Overall Group Level for Positive versus Neutral and Negative versus Neutral Contrasts

Region	BA	Size (k)	MNI Coordinates x, y, z	Z
pos>neutr				
Occipital Lobe				
Left Cuneus	19	572	-20 -98 20	6.82
Left Cuneus	18		-8 -100 4	4.85
Left Middle Occipital Gyrus	18		-14 -94 6	4.68
Left Lingual Gyrus	19	40	-28 -60 2	5.24
Right Lingual Gyrus	18	21	14 -76 -6	4.11
Right Lingual Gyrus	19	17	26 -74 -10	3.83
Left Fusiform Gyrus	19	11	-28 -78 -16	3.89
neg>neutr				
Temporal Lobe				
Right Middle Temporal Gyrus	39		46 -72 12	9.11
Parietal Lobe				
Right Precuneus	19	20	26 -80 42	5.04
Occipital Lobe				
Left Fusiform Gyrus	19	8101	-26 -56 -8	9.89
Right Fusiform Gyrus	19		26 -64 -6	8.41
Limbic Lobe				
Left Parahippocampal Gyrus		11	-26 -20 -16	4.59
Right Posterior Cingulate	30	17	24 -60 12	4.16
Left Uncus	28	22	-20 -4 -24	4.02

Note. Peak voxel coordinates, k >10, p = .001, uncorrected. pos = positive, neg = negative, neutr = neutral. Tal = Talairach. BA = Brodmann area. MNI = Montreal Neurological Institute.

Table 11

Study 2 Coordinates of Significant Activation in Regions of Interest (ROIs) for Positive versus Neutral Contrast as Predicted from SPS, Controlling for Neuroticism and Introversion

ROI	Location	Size	MNI Coordinates x, y, z	Z	*p*
21 -6 -11	R putamen	23	24 2 -6	4.90	.02
	R globus pallidus		22 -2 -8	4.43	.02

Note. Peak voxel coordinates. FDR=.05, k>10. R = right. MNI = Montreal Neurological Institute.

Table 12

Study 2 Coordinates of Significant Whole-Brain Activation for Sensory Processing Sensitivity (SPS) Status, SPS Residual (Controlling for Neuroticism and Introversion), and SPS by Parenting Interaction for Contrasts of Interest

Contrast and Region	BA	Size	MNI Coordinates x, y, z	Z
pos>neutr predicted by SPS				
Right Posterior lobe- Cerebellar Tonsil		47	36 -56 -40	4.03
Right Superior Frontal Gyrus	8	26	18 44 50	3.4
pos>neutr predicted by SPS residual				
Temporal Lobe				
Left Middle Temporal Gyrus	21	304	-54 -18 -20	4.81
Left Inferior Temporal Gyrus	20		-52 -26 -18	4.07
Right Caudate	Caudate Tail	44	34 -16 -12	3.93
Left Angular Gyrus	39	86	-36 -64 34	4.08
Left fusiform gyrus	20		-38 -22 -26	3.72
Frontal Lobe				
Left Superior Frontal Gyrus	8	25	-12 28 52	3.60
Left Middle Frontal Gyrus	6	105	-34 10 58	4.45
Left Middle Frontal Gyrus	6		-24 18 58	3.36
Left Middle Frontal Gyrus	6		-42 10 56	3.26
Left Middle Frontal Gyrus	9	122	-48 16 34	4.10
Left Middle Frontal Gyrus	9		-36 10 32	3.74
Left Inferior Frontal Gyrus	13	48	-34 6 -12	4.59
Limbic/Sub-lobar				
Left Parahippocampal Gyrus	28	67	-18 -12 -26	4.9
Left Claustrum		117	-30 -4 14	4.37
Left Lentiform Nucleus	Putamen		-22 -10 6	3.96
Left Lentiform Nucleus	Lateral Globus Pallidus		-18 -4 -2	3.35
Left Thalamus	Anterior Nucleus	79	-2 0 8	3.98

Right Lentiform Nucleus	Putamen	78	22 4 -6	3.95
Left Cingulate Gyrus	31	104	0 -34 38	3.86
Left Cingulate Gyrus	31		0 -46 32	3.37
Right Caudate	Caudate Body	38	16 0 16	3.76
Left Cingulate Gyrus	24		0 -14 40	3.37
Posterior lobe				
Left inferior temporal gyrus		370	-38 -74 -40	4.56
Left declive			-22 -76 -28	4.17
Left Uvula			-30 -80 -32	3.67
Left Uvula		143	-10 -66 -44	4.34
Left Inferior Semi-Lunar Lobule			-2 -60 -50	4.01
Left Cerebellar Tonsil			-14 -54 -50	3.16
Left Declive		54	-8 -80 -28	4.26
Right Declive		1384	24 -80 -26	6.06
Right Declive			18 -74 -30	5.17
Right Declive			32 -72 -30	4.92
Right Cerebellar Lingual		60	2 -44 -12	3.66
neg>neutr predicted by SPS residual				
Right Posterior Lobe-Declive		78	30 -76 -29	3.84
Right Posterior Lobe-Declive			22 -78 -26	3.78
neg>neutr predicted by SPS status X Parenting				
L Claustrum		68	-28-18 18	4.17
Left Inferior Temporal Gyrus	20	4	-52 -26 -6	1.37

Note. All coordinates at *p*=.001, uncorrected, k>25, except for the neg>neutr contrast for SPS status X Parenting, which is at p=.005, k>0. pos = positive, neg = negative, neutr = neutral. MNI = Montreal Neurological Institute. SPS = Sensory Processing Sensitivity. SPS residual = Sensory Processing Sensitivity controlling for neuroticism and introversion.

Table 13

Study 2 Coordinates of Significant Whole-Brain Activation for Sensory Processing Sensitivity (SPS) Status for Neutral versus Negative Contrast

Contrast and Region	BA	Size	MNI Coordinates x, y, z	Z
neutr>neg predicted by SPS				
Left Middle Frontal Gyrus	6	127	-26 2 54	4.49
Right Middle Frontal Gyrus	8	38	30 8 42	3.56
Right Inferior Parietal Lobule	40	29	50 -40 48	3.38
Right Inferior Parietal Lobule	40		46 -44 56	3.38

Note. All coordinates at p=.001, uncorrected, k>25, neg = negative, neutr = neutral. MNI = Montreal Neurological Institute. SPS = Sensory Processing Sensitivity

Table 14

Study 2 Talairach Coordinates Corresponding to Significant Whole-Brain Activation for Sensory Processing Sensitivity (SPS) Residual and Extraversion

Region	Contrast (Source)	
	Pos>neg correlated with Extraversion (Canli et al., 2001)	Pos>neutr predicted by SPS residual (Study 2)[b]
Left Putamen	-30 -7 -9	-22 -9 6
Left lateral globus pallidus	-21 -8 5	-18 -4 -1
Left middle frontal gyrus	-37 15 43	-34 12 53
Left frontal lobe	-24 10 49	-24 20 52[c]

Note. SPS residual = SPS status, controlling for neuroticism and introversion
[a] Clusters of significant correlations were determined as specified in Canli et al., 2001.
[b] Peak voxel coordinates at p = .001, uncorrected, k>25.
[c] local peak in cluster centered on -34, 12, 53

Figure 1. Flow of participants through each stage of study

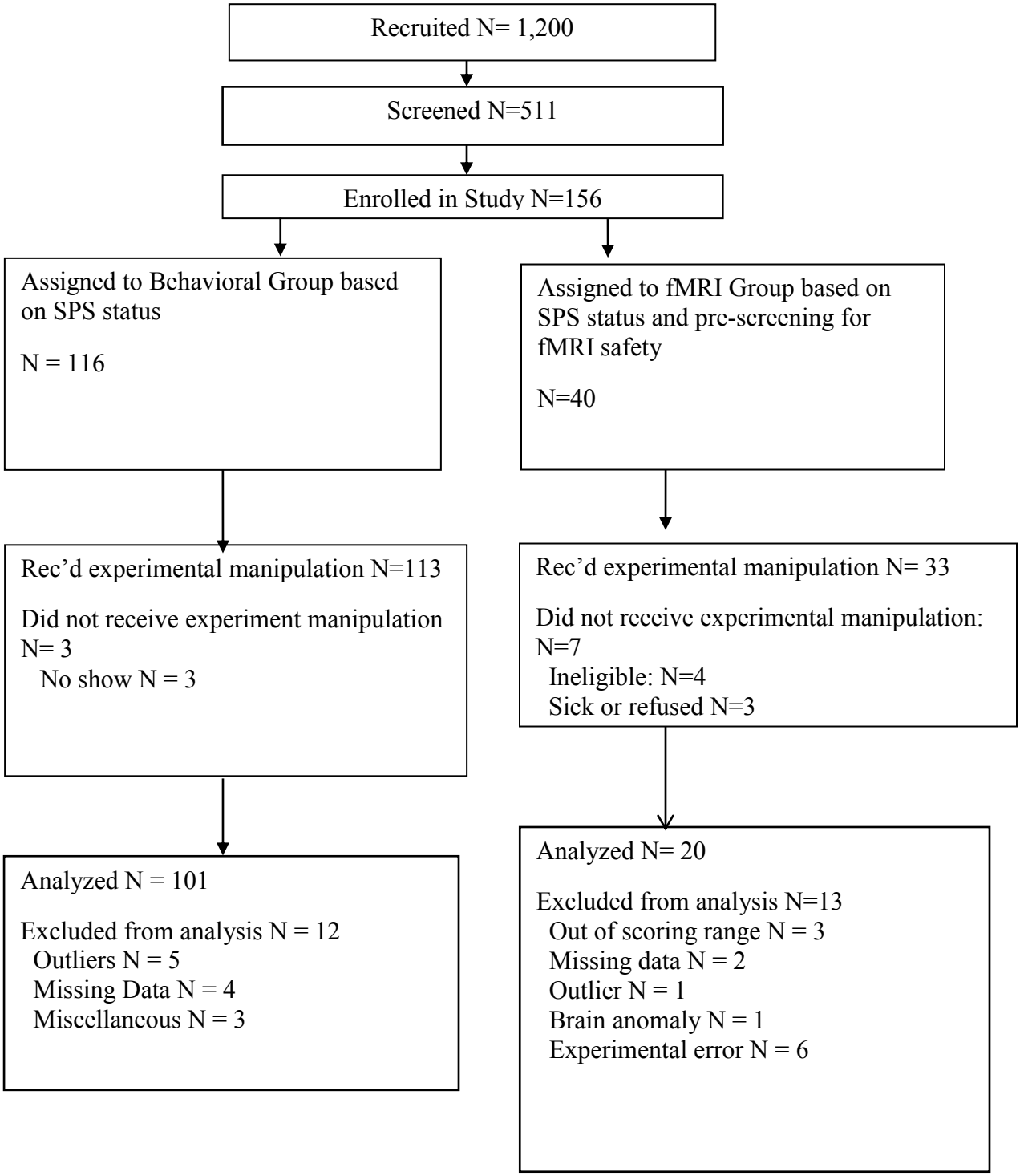
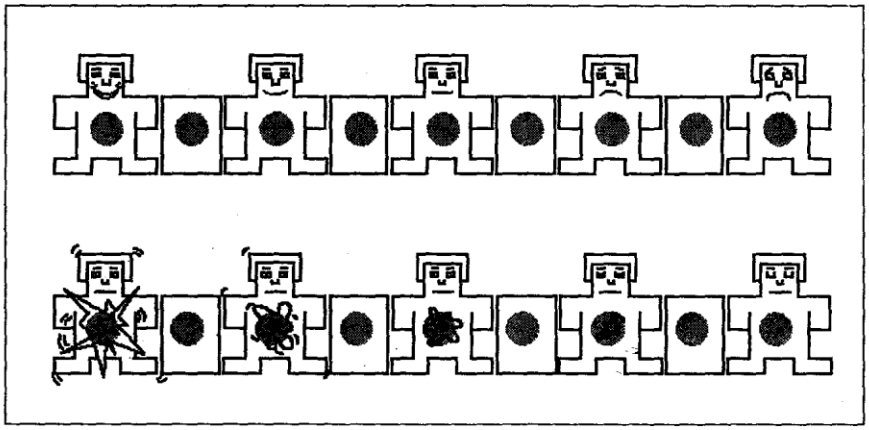


Figure 2. Picture similar to positive picture from the International Affective Picture System. (Actual pictures are not permitted to be reproduced) (IAPS; P. J. Lang, et al., 2005)

Figure 3. Self-Assessment Manikin for rating valence (top) and arousal (bottom). The reported studies measure valence as an exploratory variable. SELF ASSESSMENT MANIKIN Reprinted by permission. © Peter J. Lang 1994



Scoring: **9 8 7 6 5 4 3 2 1**

Figure 4. Relation of weighted 7-scale parenting score to arousal ratings in response to positive IAPS pictures at high and low levels of SPS

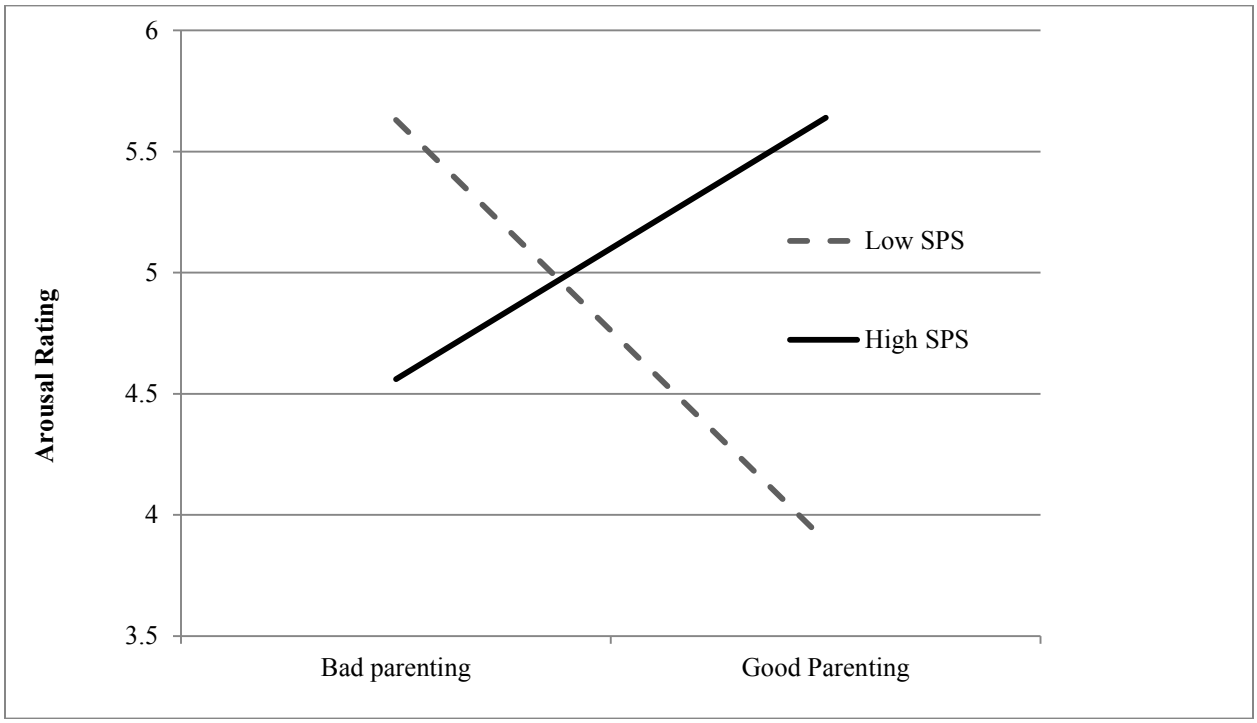


Figure 5. Relation of PBI-Father Care subscale score to arousal ratings in response to positive IAPS pictures at high and low levels of SPS

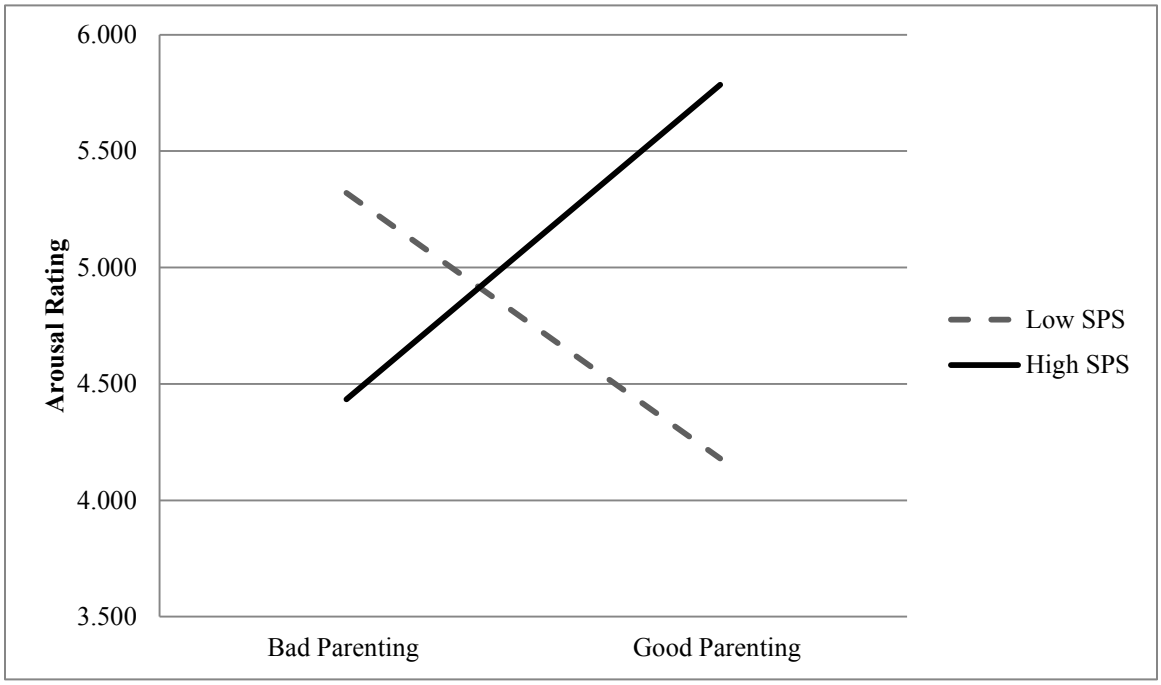


Figure 6. Relation of PBI-Father Overprotection subscale score to arousal ratings in response to positive IAPS pictures at high and low levels of SPS

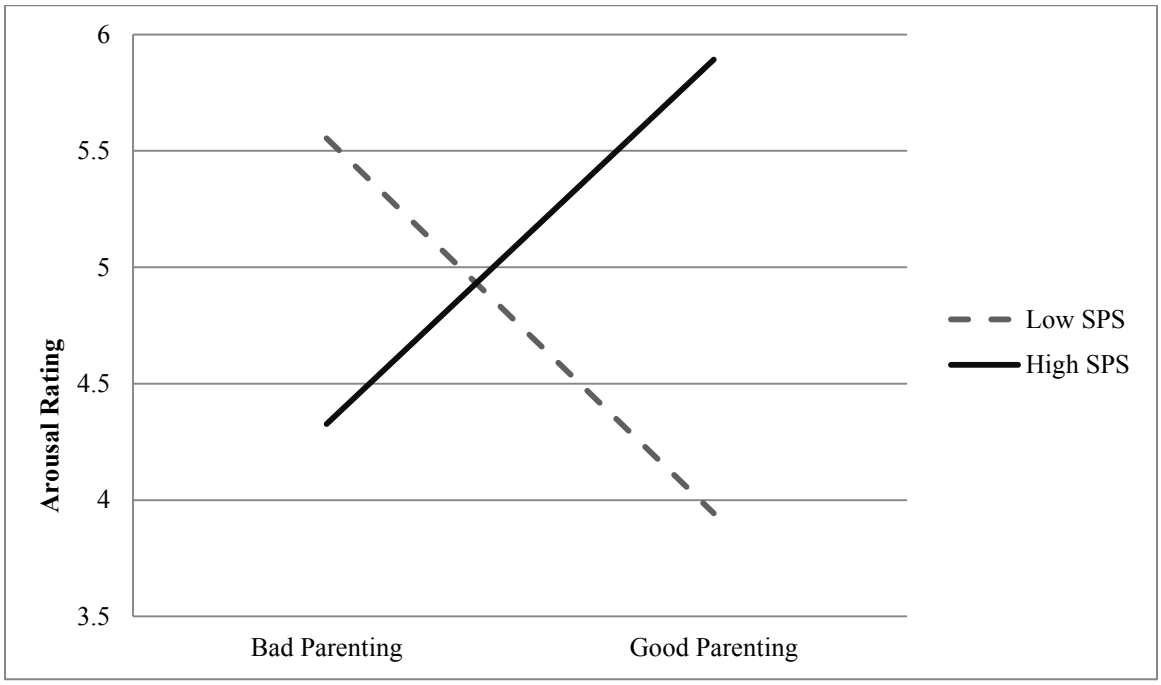


Figure 7. BOLD activation. ROI analysis. BOLD in the right putamen/right globus pallidus. Group average activation data for the regression of the standardized residual of the HSP mean on the positive > neutral contrast. Lighter color corresponds to greater activation. MNI coordinates for two local maxima > 4 mm apart at 24, 2, -6 and 22, -2, -8. FDR= .05, k = 23.

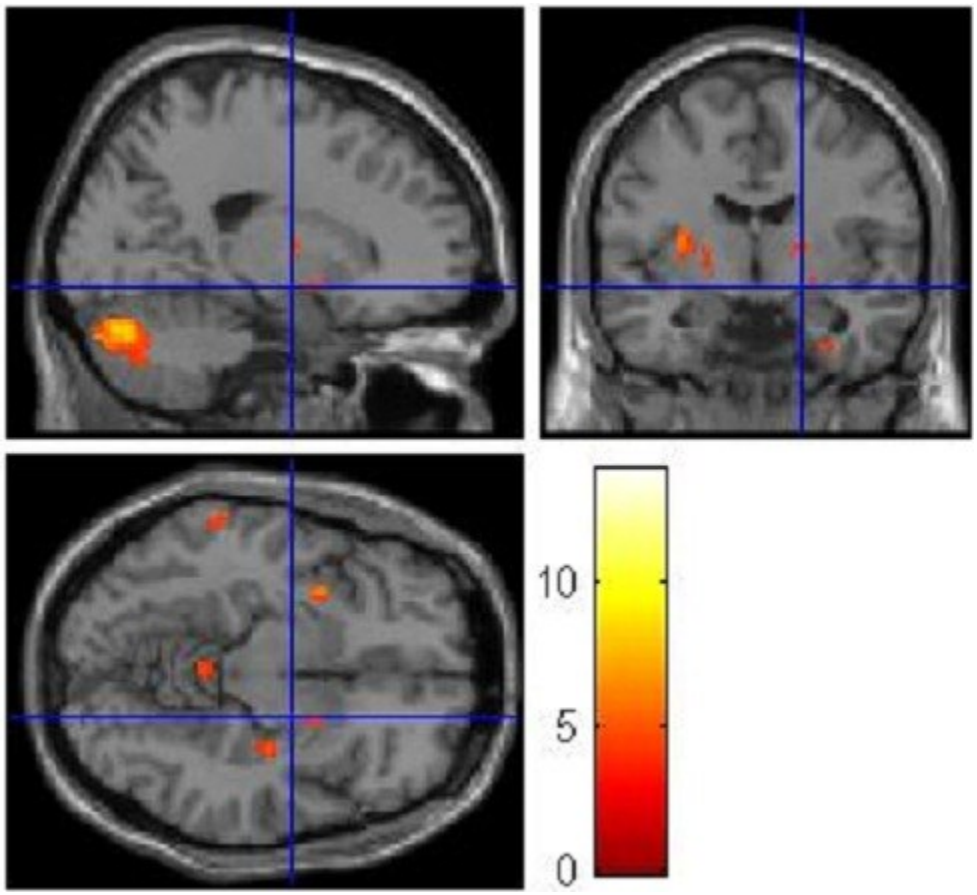
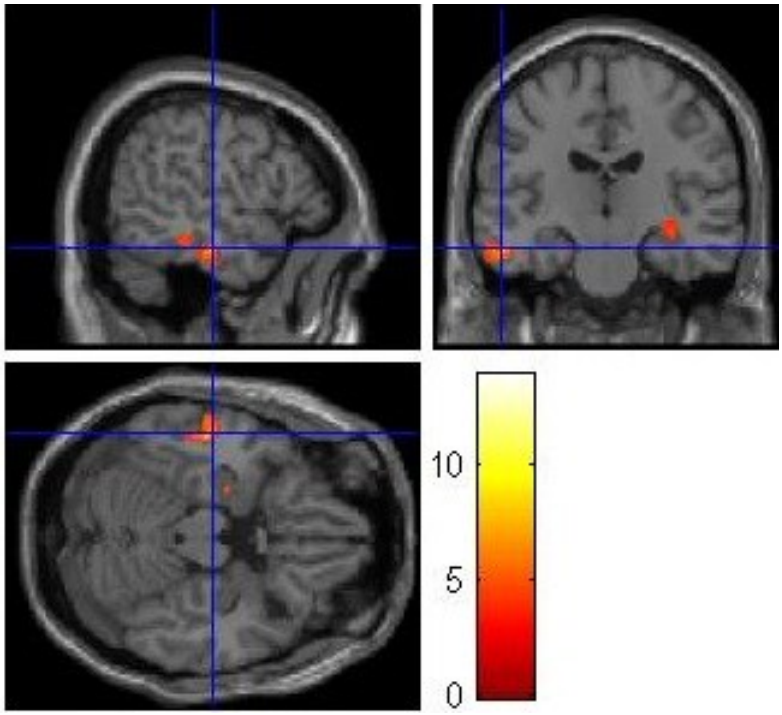


Figure 8. BOLD activation. BOLD in the left middle temporal gyrus. Group average activation data for the regression of the standardized residual of the HSP mean on the positive > neutral contrast. Lighter color corresponds to greater activation. MNI co-ordinates for the center of the activation cluster were –54, -18, -20.



Appendix A

Life Experience Questionnaire

Have any of the following happened to you in the first 16 years of your life? If you state "yes", please indicate approximately what year it happened or your age at the time (if it happened more than once, try to indicate when for each occurrence)

Event	Y N	When	Additional Info:
Serious illness, accident or diagnosis of a close family member (child ,parent, sibling, grandparent)	☐☐		
Serious illness, accident or diagnosis of a boyfriend/girlfriend	☐☐		
Death of a family member	☐☐		
Death of a boyfriend/girlfriend	☐☐		
Death of a friend (other than boyfriend/girlfriend)	☐☐		
Death of a beloved pet	☐☐		
Parents separated	☐☐		
Constant arguments between family members	☐☐		
Broke up with boyfriend/girlfriend	☐☐		
Serious problems in relationships with friends	☐☐		
Started school	☐☐		
You/partner had an unplanned pregnancy	☐☐		
You/a partner had an abortion	☐☐		
Serious physical illness – unable to carry out normal activities	☐☐		
Been physically assaulted or mugged	☐☐		
Been sexually assaulted	☐☐		
Any other stressful event (car crash, house fire, earthquake, military combat) please specify	☐☐		

Appendix B

Example of screening phone script

IRB Approved 4/27/09
Expiration Date: 4/26/10
CORIHS Stony Brook University

If you decide to be in this study, your part will involve filling out a personality questionnaire. You will also be in a thinking style experiment asking you to report the direction an arrow is pointing in and an experiment asking you to rate some pictures on how excited or calm and who happy or sad they make you feel. Then you will donate some cheek cells that will be sent to scientists specializing in genetic analysis. The genetic analysis will look for genes that are believed to be related to personality traits.

The following risks/discomforts may occur as a result of you being in this study: The genetic analysis to be conducted on your tissue in this study may pose future risks that are not known at this time. There is no benefit or cost to you expected as a result of you being in this study. You will receive $7.50 per hour for participating. The study should take about 1.5 -2 hours. Your alternative to being in this study is to simply not participate

Do you have any questions about the study or your rights as a research subject?
IF YES, GIVE THEM THE FOLLOWING INFORMATION

Questions re: study: you may contact Dr. Arthur Aron at telephone # (631- 632-7707).
Questions about your rights as a research subject: Ms. Judy Matuk, Committee on Research Involving Human Subjects, (631) 632-9036, judy.matuk@stonybrook.edu.

PART 1. **Asked of all participants**

1. Do you smoke? _____YES _____NO

2. On any single occasion during the past 3 months, have you had more than 5 drinks containing alcohol?" _____YES _____NO

3. Do you take drugs other than drugs prescribed to you or over-the-counter medications?
_____YES_____NO

4. Have you ever seen a neurologist? Do you have any history of neurological illness?
_____YES_____NO

5Are you currently on any medication for a neurological condition?
_____YES _____N0

6. Have you ever been diagnosed with an anxiety disorder, depression, or psychotic disorder? _____YES_____NO

NO to ALL of the above questions > CONTINUE

6. Have you ever had an fMRI scan before? _____ _____

YES TO Q6> INCLUDE
NO TO Q6 > INCLUDE

Appendix C

Study 1 Nonsignificant Results for Interaction Effects in Hierarchical Multiple Regression Analyses Predicting Arousal Response Time (RT), Arousal Response (Resp) Rating, Valence (Val) Response Time, and Valence Response Rating from Childhood Environment X Sensory Processing Sensitivity (SPS) Interaction

Model	Predictor	Beta	p
SPS & 7-scale parenting			
Negative Valence RT regressed on SPS & 7-scale parenting	SPS status X weighted 7-scale parenting	.05	.58
Negative Valence Response regressed on SPS & 7-scale parenting	SPS status X weighted 7-scale parenting	.01	.96
Negative Arousal Response regressed on SPS & 7-scale parenting	SPS status X weighted 7-scale parenting	-.06	.70
Positive valence RT regressed on SPS &7-scale parenting	SPS status X weighted 7-scale parenting		
SPS & PBI-Mother Care			
Negative valence RT regressed on SPS & PBI-Mother Care	SPS status X PBI – Mother Care	-.01	.98
Negative valence response regressed on SPS & PBI-Mother Care	SPS status X PBI – Mother Care	.14	.51
Negative arousal response regressed on SPS & PBI-Mother Care	SPS status X PBI – Mother Care	.04	.81
Positive valence RT regressed on SPS & PBI-Mother Care	SPS status X PBI – Mother Care	-.04	.71
Positive valence response regressed on SPS & PBI-Mother Care	SPS status X PBI – Mother Care	-.21	.39
Positive arousal response regressed on SPS & PBI-Mother Care	SPS status X PBI – Mother Care	-.28	.13

SPS status X PBI-Mother overprotection

Negative Valence RT regressed on SPS, PBI-Mother overprotection	SPS status X PBI-Mother overprotection	.21	.24
Negative Valence Response regressed on SPS, PBI-Mother overprotection	SPS status X PBI-Mother overprotection	.26	.43
Negative Arousal Response regressed on SPS, PBI-Mother overprotection	SPS status X PBI-Mother overprotection	-.08	.77
Positive Valence RT regressed on SPS, PBI-Mother overprotection	SPS status X PBI-Mother overprotection	-.04	.71
Pos Val Response regressed on SPS, PBI-Mother overprotection	SPS status X PBI-Mother overprotection	-.22	.52

SPSstatus X PBI Father care

Negative Valence RT regressed on SPS, PBI-father care	SPSstatus X PBI-Father care	.02	.91
Negative Valence Response regressed on SPS, PBI-father care	SPSstatus X PBI-Father care	-.14	.63
Negative Arousal Response regressed on SPS, PBI-father care	SPSstatus X PBI-Father care	-.02	.94
Pos Val RT regressed on SPS, PBI-father care	SPSstatus X PBI-Father care	.08	.57
Pos Val Response regressed on SPS, PBI-father care	SPSstatus X PBI-Father care	.49	.14

SPS status X PBI-Father overprotection

Negative Valence RT regressed on SPS status, PBI Father overprotection	SPS status X PBI-Father overprotection	.09	.63
Negative Valence Response regressed on SPS status, PBI Father overprotection	SPS status X PBI-Father overprotection	.39	.23

Neg Arousal Response regressed on SPS status, PBI Father overprotection,	SPS X Father-overprotection	.14	.59
Pos Val RT regressed on SPS status, PBI-Father overprotection	SPS X Father-overprotection	-.05	.77
Pos Val Response regressed on SPS status, PBI-Father overprotection	SPS X Father-overprotection	.49	.14
SPS X Life Experience			
Negative Valence RT regressed on SPS, life experience	SPS X Life Experience	-.07	.92
Neg Valence Response regressed on SPS, life experience	SPS X Life Experience	-.68	.59
Neg Arousal Response regressed on SPS, life experience	SPS X Life Experience	-.86	.41
Pos Val RT regressed on SPS, life experience	SPS X Life Experience	-.34	.56
Pos Val Response regressed on SPS, life experience ,	SPS X Life Experience	-.33	.81
Pos arousal resp regressed on SPS, life experience	SPS X Life Experience	.95	.37

Notes. All results shown above are for interaction (product term) with neutral arousal response rating, then centered main effects, entered first. PBI = Parental Bonding Instrument.
.

Appendix D

Means and Standard Deviations for Arousal Score, Valence Response Time (RT), and Valence Score for Overall Group

Variable	N	M	SD
Negative minus Neutral Arousal			
Negative Arousal Score	96	5.04	1.90
Neutral Arousal Score	96	3.19	1.11
Positive minus Neutral Arousal			
Positive Arousal Score	96	5.00	1.55
Neutral Arousal Score	96	3.19	1.11
Negative minus Neutral Valence			
Negative Valence Score	88	2.51	.79
Neutral Valence Score	88	4.56	.56
Positive minus Neutral Valence			
Positive Valence Score	91	6.60	.79
Neutral Valence Score	91	4.54	.62
Negative minus Neutral Valence RT			
Negative Valence RT	96	1514.67	496.47
Neutral Valence RT	96	1464.81	476.45
Positive minus Neutral Valence RT			
Positive Valence RT	95	1408.43	453.18
Neutral Valence RT	95	1457.02	472.79

Notes. Scores are reported on a scale from 1 through 9, with 9 being the most positive score and 1 being the most negative score. Ns differ between arousal scores, valence scores and valence RTs; as well as between negative and positive pictures, due to a differing number of missing values for each of the previously mentioned dependent variables.

Appendix E

Study 1 Hierarchical Multiple Regression Analyses Predicting Arousal Response Rating (Resp), Valence Response Time (Val Resp RT), and Valence Response Rating (Val Resp) from Parenting

Model	Predictor	N	Beta[a]
Analysis with PBI-Mother overprotection			
Negative Val RT	Neutral Val RT	96	.83***
	PBI-Mother Overprotection		.05
Negative Val Resp	Neutral Val Resp	88	.39***
	PBI-Mother Overprotection		-.01
Negative Arousal Resp	Neutral Arousal Resp	96	.56***
	PBI-Mother Overprotection		-.09
Positive Val RT	Neutral RT	95	.87***
	PBI-Mother Overprotection		.05
Positive Val Resp	Neutral Resp	91	.03
	PBI-Mother Overprotection		-.01
Positive Arousal Resp	Neutral Arousal Resp	96	.54***
	PBI-Mother Overprotection		-.004
Analysis with PBI-Mother care			
Negative Val RT	Neutral RT	96	.83***
	PBI-Mother care		.06
Negative Val Resp	Neutral Resp	88	.39***
	PBI-Mother Care		.09
Negative Arousal Resp	Neutral Arousal Resp	96	.56***
	PBI-Mother Care		-.01
Positive Val RT	Neutral RT	95	.87***
	PBI-Mother Care		-.01
Positive Val Resp	Neutral Resp	91	.03
	PBI-Mother Care		-.07
Positive Arousal Resp	Neutral Arousal Resp	96	.54***
	PBI-Mother Care		-.01
Analysis with PBI-Father overprotection			
Negative Val RT	Neutral RT	96	.83**
	PBI-Father Overprotection		-.10†

Negative Val Resp	Neutral Resp	88	.39
	PBI-Father Overprotection		-.14
Negative Arousal Resp	Neutral Arousal Resp	96	.56***
	PBI-Father Overprotection		-.10
Positive Val RT	Neutral RT	95	.87***
	PBI-Father Overprotection		.01
Positive Val Resp	Neutral Resp	91	.03
	PBI-Father Overprotection		.14
Positive Arousal Resp	Neutral Arousal Resp	96	.54***
	PBI-Father Overprotection		.07

Analysis with PBI-Father Care

Negative Val RT	Neutral RT	96	.83***
	PBI-Father Care		-.01
Negative Val Resp	Neutral Resp	88	.39***
	PBI-Father Care		.14
Negative Arousal Resp	Neutral Arousal Resp	96	.56***
	PBI-Father Care		-.01
Positive Val RT	Neutral RT	95	.87***
	PBI-Father Care		-.08
Positive Val Resp	Neutral Resp	91	.03
	PBI-Father Care		-.21
Positive Arousal Resp	Neutral Arousal Resp	96	.54***
	PBI-Father Care	96	-.09

Analysis with 7-scale Parenting

Negative Val RT	Neutral RT	96	.83***
	7-Scale Parenting		.03
Negative Val Resp	Neutral Resp	88	.52***
	7-Scale Parenting		.06
Negative Arousal Resp	Neutral Arousal Resp	96	.56**
	7-Scale Parenting		-.002
Positive Val RT	Neutral RT	95	.87***
*	7-Scale Parenting		-.05
Positive Val Resp	Neutral Resp	91	.03
	7-Scale Parenting		-.12
Positive Arousal Resp	Neutral Arousal Resp	96	.54***

	7-Scale Parenting	**.00**

Notes. Neutral arousal response rating entered first as a control. Higher scores on the overall weighted 7-Scale Parenting sum indicate positive childhood experience. Scoring on individual scales: high scores on PBI Care mean a negative childhood; high scores on PBI overprotection mean a positive childhood. PBI = Parental Bonding Instrument.

[a]Standarized regression coefficient for this variable at the step when it is first added to the equation.

†p< .10, **p< .05, **p<.01**, p <.001****

Appendix F

Significant Brain Activation for Whole-Brain Analysis for Neutral (Neutr) versus Negative (Neg) and Neutral (Neutr) versus Positive (Pos) Contrasts for Overall Sample

Region	BA	Size	MNI Coordinates x, y, z	Z
neutr>neg				
Temporal Lobe				
Right Superior Temporal Gyrus	22	432	62 -4 8	7.77
Right Superior Temporal Gyrus	22		60 2 -2	4.46
Left Middle Temporal Gyrus	21	281	-64 -40 -12	6.49
Left Inferior Temporal Gyrus	20		-58 -34 -18	5.51
Left Sub-Gyral	37		-48 -44 -4	4.95
Right Superior Temporal Gyrus	41		38 -40 10	4.71
Right Fusiform Gyrus	20	28	52 -30 -24	5.75
Right Inferior Temporal Gyrus	20		62 -22 -24	3.95
Frontal Lobe				
Left Medial Frontal Gyrus	10	1355	-18 44 -2	8.56
Left Precentral Gyrus	43		-62 -6 10	4.58
Left Superior Frontal Gyrus	6		-16 -10 62	6.16
Left Precentral Gyrus	6		-18 -16 68	5.99
Right Superior Frontal Gyrus	6	75	26 20 62	4.98
Left Superior Frontal Gyrus	6	148	-26 18 62	4.91
Left Superior Frontal Gyrus	6		-16 12 64	4.45
Left Superior Frontal Gyrus	6		-14 12 54	4.41
Left Middle Frontal Gyus	8		-28 34 42	4.29
Left Superior Frontal Gyrus	8		-26 42 42	4.24
Left Middle Frontal Gyrus	9		-28 38 32	4.20
Left Precentral Gyrus	6		-32 -12 66	4.11
Right Middle Frontal Gyrus	8		30 30 42	4.06
Left Precentral Gyrus	4		-38 -18 50	3.96
Right Middle Frontal Gyrus	9		34 44 28	3.93
Parietal Lobe				
Left Postcentral gyrus	43	357	-48 -12 16	7.05
Right Postcentral Gyrus	3	2296	28 -30 62	6.56
Left Inferior Parietal Lobule	40	656	-48 -48 42	6.24
Left Inferior Parietal Lobule	40		-42 -60 42	6.08
Left Angular Gyrus	39		-32 -60 38	6.05
Right Postcentral Gyrus	43		48 -12 20	4.54

Right inferior Parietal Lobule	40	104	42 -46 42	4.53
Right inferior Parietal Lobule	40		52 -50 42	4.23
Right inferior Parietal Lobule	40		48 -46 50	3.72
Left Precuneus	7	41	-4 -70 48	3.99
Limbic Lobe				
Right Anterior Cingulate	32		14 44 -4	6.34
Left Anterior Cingulate			-12 36 2	5.80
Left Cingulate Gyrus	23	14	-4 -14 32	4.75
Right Anterior Cingulate	24	32	0 22 2	4.70
Sub-Lobar				
Left Insula	13		-36 -22 18	5.47
Right Insula	13	68	34 -36 18	6.16
Right Insula	13	163	42 -16 14	5.48
Right Caudate		40	22 -38 8	5.42
neutr>pos				
Frontal				
Left Superior Frontal Gyrus	6	123	-14 -6 64	6.93
Left Superior Frontal Gyrus	6		-14 -14 62	5.18
Left Inferior Frontal Gyrus	10	29	-40 50 0	4.99
Temporal				
Right Superior Temporal Gyrus	22	188	60 -52 18	5.56
Right Superior Temporal Gyrus	13		48 -42 16	4.15
Right Superior Temporal Gyrus	13		50 -40 24	3.90
Left Middle Temporal Gyrus	21	98	-58 -48 0	4.94
Left Middle Temporal Gyrus	21		-64 -46 -6	4.51
Parietal Lobe				
Left Postcentral Gyrus	7	148	-20 -48 64	6.06
Left Precuneus	7		-4 -52 54	4.50
Left Precuneus	7		-16 -48 52	4.18
Right Superior Parietal Lobule	7	271	12 -64 54	6.01
Right Precuneus	7		12 -50 50	4.27
Right Postcentral gyrus	7		16 -50 62	4.19

Notes. *(p* < 001; k > 25 voxels), BA = Brodmann Area.