The Effect of Social Support on Frontal Asymmetry: Neural Reactivity to Social Support and Longitudinal Outcomes

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Abstract

The perception of adequate social support is associated with an extension of life expectancy of the same magnitude as many recommended health behaviors (Holt-Lunstad et al., 2010). Mechanistic pathways proposed to explain this phenomena include biological (Ozbay et al., 2007; Reblin & Uchino, 2008), behavioral (Reblin & Uchino, 2008; Umberson, 1987), and psychological (Uchino et al., 1996, 2012) pathways. However, the extant literature has not examined the means by which perceived social support exerts benefits through these pathways, and there is a need for theory-driven investigations into intermediary mechanisms. This dissertation study proposes a theoretical framework, Social Augmentation of Approach/Avoidance Theory (SAAT), which establishes falsifiable hypotheses about a specific intermediary pathway: social alterations of approach and avoidance motivation. This dissertation then systematically tests hypotheses generated by SAAT through a series of analyses utilizing electroencephalographic (EEG) and functional resonance magnetic imagining (fMRI) data.

The participants in the two datasets used in this dissertation (*N* = 74 and 71 respectively) underwent a threat of shock task, during which they were either alone or being supported by a chosen partner. Partners supported the participants being threatened by holding hands. This task has been shown to index neural differences between the two conditions (i.e., being threatened while alone and being threatened while holding a partner's hand) associated with decreased threat processing (L. A. Beckes et al., 2020; Coan, Schaefer, et al., 2006; Maresh et al., 2013). Participants in the first dataset completed measures of current psychopathology during the visit where they underwent the hand holding task. Participants in the second dataset were part of a larger, longitudinal study, with measure of psychopathology and physiological health collected extensively over 15 years. Participants in the first study underwent the threat of shock task with support from a romantic partner. Participants in the second study underwent the task with a partner of their choosing. These included a mixture of friends, cohabiting romantic partner, and non-cohabiting romantic partners.

Study 1 tested whether receiving social support, in the form of supportive touch during threat of shock, is associated with an increase in approach motivation compared to being alone. I utilized a well-established index of approach/avoidance motivation, frontal alpha asymmetry (Coan & Allen, 2003a, 2003b, 2004; Kelley et al., 2017; Stewart et al., 2011, 2014), processed using EEG taken during the hand holding task. I also investigated current psychopathology as a moderator of frontal asymmetry during the task. Results indicated an overall decrease in left frontal activity when seeing threatening cues, but no effect on right frontal activity or the overall asymmetry index. Similarly, left frontal activity was sensitive to current depression symptoms and condition (alone or with partner), but neither right frontal activity nor overall asymmetry was affected.

Study 2 expanded on the initial findings in Study 1 by incorporating longitudinal data and testing the sensitivity of asymmetry in specific brain systems to supportive touch during threat. Participants were scanned using fMRI during the same hand holding task outlined above. Asymmetry was calculated using a previously validated fMRI laterality index for masks of the amygdala and an executive control network (ECN) containing the dorsolateral prefrontal cortex (dlPFC). These laterality indexes were calculated from contrasts of activity during threat cues minus activity during safety cues. I examined whether asymmetry in either brain system was altered when seeing different cues, and whether previous psychopathology and the relationship with the supporting individual moderated these effects. Results indicated more leftward activity when receiving social support in both the amygdala and ECN. However, psychopathology factors moderated this pattern in the amygdala. Hand holding was associated with different changes in amygdala laterality depending on the interaction between relationship type and previous depressive episodes. Anxiety history also moderated the effect of hand holding on amygdala laterality.

I continued my analyses in study 2 by examining whether individual differences in laterality sensitivity to hand holding mediated or moderated the relationship between perceived social support and a number of physiological health and behavior measures taken in the years following participants visit to the scanner. Results of these analyses did not align with hypotheses generated theoretically, and no significant moderation or mediation effects were found.

Results of these two studies were mixed when it came to testing hypotheses generated from the SAAT framework. I conclude this dissertation by discussing the results in the context of the extant literature, elaborating on potential limits of the presented studies, and future directions to further test intermediary pathways between social support, psychological health outcomes, and physical health outcomes.

Table of Contents

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The Effect of Social Support on Frontal Asymmetry: Neural Reactivity to Social Support and Longitudinal Outcomes

Introduction

Having adequate social relationships (compared to having poor or insufficient relationships) is associated with an extension of the lifespan by the same magnitude as not smoking and by a greater magnitude than not being obese or being physically active (Holt-Lunstad et al., 2010). Here, I investigate approach and avoidance motivation, indexed using a neural marker, as a potential mechanism by which social relationships may contribute to improved physical and psychological health. The purpose of this study is to further our understanding of how social support affects approach and avoidance motivation, differences in these effects based on psychopathology symptoms, and what role these effects play in the relationship between perceived social support and physical health.

Studies examining potential pathways by which social support promotes health and well-being have focused on three mediation models: 1) biological mechanisms, especially inflammatory processes (Ozbay et al., 2007; Reblin & Uchino, 2008); 2) behavioral mechanisms, especially the influence of social support on health behaviors (Reblin & Uchino, 2008; Umberson, 1987); and 3) psychological mechanisms, such as depression, perceived stress, and other affective processes (Uchino et al., 1996, 2012). Findings across these three lines of study have been inconsistent. Biological mechanism studies often find associations between perceived social support and inflammatory markers can only be found for specific populations and specific cytokines, and different studies often fail to replicate each other's findings (Coussons-Read et al., 2007; Graham et al., 2006; Marsland et al., 2007; McDade et al., 2006; Reblin & Uchino, 2008). Health-related behaviors often correlate with perceived social support (Reblin & Uchino, 2008), yet several studies find that these behaviors do not mediate the relationship between social support and physiological indicators of health (Uchino et al., 1996). Similarly, while perceived social support has been linked to reductions in stress and depression, this relationship does not appear to mediate the connection between social support and physiological indicators of health (Reblin & Uchino, 2008; Uchino et al., 2012).

Reblin and Uchino (2008) suggested that examining specific brain regions linked to social support might help clarify mixed findings in the research linking social support to health outcomes. In this dissertation, I use collected neurophysiological data from a well-validated social support task, supportive hand-holding during threat of pain (cf., Coan, Schaefer, et al., 2006; Maresh et al., 2013), to understand the effect of social support in augmenting a well-validated biomarker of approach and avoidance behavior, frontal cortex asymmetry during an emotional challenge (Coan & Allen, 2003b; Kelley et al., 2017; Stewart et al., 2011, 2014). I also examine whether lifetime vulnerability to psychopathology linked to approach and avoidance behaviors moderates this effect using a separate, longitudinal dataset with extensive historic data on depression and anxiety symptoms (cf., McElhaney et al., 2006), Finally, using the same longitudinal dataset, I examine whether modulation of approach/avoidance motivation, indexed using frontal asymmetry, moderates and/or mediates the relationship between perceived social support and biological, behavioral, and psychological correlates of physical health.

My dissertation is innovative in three ways. First, this project is the first to examine the effect of social ecology on a neural marker of approach and avoidance motivation, combining methodologies and theories from different lines of affective, clinical, and social neuroscience. Second, it is the first investigation involving an approach and avoidance biomarker to combine controlled, laboratory-assessed responses to later physiology and real-world behaviors. Third, the proposed project will be the first to use a neural marker to test a complex longitudinal relationship between perceived social support and physical and mental health.

This dissertation pursues three aims: 1) to characterize the effect of social support, in the form of supportive touch, on a neural index of approach and avoidance motivation, 2) to understand the relationship between affective disorder symptoms and the effect of supportive touch on approach and avoidance motivation, and 3) to evaluate whether changes in approach and avoidance motivation in response to supportive touch moderate and/or mediate the relationship between perceived social support and indicators of physical health. To achieve these aims, self-report and neural data was analyzed from two previously collected sample, one utilizing electroencephalography (EEG) and the other using functional magnetic resonance imagining (fMRI). Study 1 investigated whether frontal alpha asymmetry (FAA), a neural marker linked to approach and avoidance motivation, was sensitive to supportive touch during a threatening task. I then evaluated whether this effect was moderated by anxiety and depression symptoms reported by participants on the day of neural data collection. Study 2 utilized a longitudinal dataset in order to address aims 2 and 3. Study 2 evaluated whether an individual's history of depression and anxiety symptoms before completing a threatening task moderated any changes to their approach and avoidance motivation when receiving supportive touch, indexed using an fMRI measure. Study 2 also investigated if neural sensitivity to approach and avoidance motivation changes moderated and/or mediated connections between perceived social support and health related outcomes obtained in the years following the fMRI session.

Background, Significance, and Theory

Perceived social support has been meta-analytically linked to significant increases in lifespan. Individuals who report having adequate social relationships are at a 50% (95% CI: 42%, 59%) reduced risk of mortality from all causes compared to individuals who report having inadequate social relationships (Holt-Lunstad et al., 2010).This reduction in mortality risk is comparable to that found for not smoking (vs. light smoking – males 47%, females 50%) and quitting smoking in patients with coronary heart disease (57%, 95% CI: 40%, 72%), and greater than that found for not being obese (23%, 95% CI: 18%, 29%) and being physically active (25%, 95% CI: 22%, 28%) (see Critchley & Capewell, 2003; Katzmarzyk et al., 2003; Shavelle et al., 2008 for effect sizes and methods, and Holt-Lunstad et al., 2010 for a full comparison with several known health risk factors). Perceived social support is also linked to decreased rates of anxiety (16% reduction, 95% CI: 9% - 24%) and depression (20% reduction, 95% CI: 14% - 25%) in a sample 4657 nonacademic staff members of a Medical University system (Roohafza et al., 2014), decreased anxiety (b = -.33) and depression (b = -.18) severity 6 months following medical interactions with primary care physicians (Dour et al., 2014), and decreased anxiety (r = -.34, 95% CI: .12, .57) and depression (r = -.37, 95% CI: .10 - .56) severity following stressful medical interactions such as chemotherapy for ovarian cancer (Hipkins et al., 2004).

Similarly, approach motivation, as opposed to avoidance motivation, has been linked to improved general health among college undergraduates (though there is evidence this effect is culturally moderated, see Tagaki, 2005 for details), improved well-being following exposure to stress among first responders (approach improvement: b = .09, avoidance deterioration b = -.20; Arble & Arnetz, 2017), and better health information seeking following a simulated health-threatening situation (see Chasiotis et al., 2019 for effect sizes of multiple mediation model). Further, trait avoidance motivation has been linked to increased risk of onset (*OR*: 1.55) and increased risk of chronic course (*OR*: 1.31) in anxiety disorders (Struijs et al., 2018) and increased anxiety (standardized β = .40) and depression (standardized β = .47) symptom severity (Struijs et al., 2017).

Social baseline theory provides a framework for integrating the similarly positive outcomes linked to high levels perceived social support and higher levels of approach motivation. Social baseline theory posits that access to social relationships engenders individuals with the expectation that situations present lower risk and require less effort than when they do not have access to social resources (Coan & Sbarra, 2015). This model of situational perception has been validated behaviorally and with neuroimaging. For example, participants in one study perceived hills to be less physically steep when a friend stood nearby than when alone (Schnall et al., 2008). Further, studies have repeatedly shown that individuals under threat of shock show diminished brain activity in areas of the brain linked to threat processing when they are with a trusted partner compared to when they are alone (L. A. Beckes et al., 2020; Coan et al., 2013; Coan, Schaefer, et al., 2006).

I argue that this reduction in perceived risk and effort that accompanies perceived social support is accompanied by a potentiation of approach motivation and an attenuation of avoidance motivation, which partially explains the relationship between perceived social support and physiological and mental health. This framework, which I call Social Augmentation of Approach/Avoidance Theory (SAAT), provides testable hypotheses that can be used to fill in gaps in the extant literature on perceived social support (Reblin & Uchino, 2008) and approach avoidance motivation (Coan & Allen, 2004).

Similar to Coan and Allen's (2004) proposal of approach and avoidance motivation as both a mediator and moderator of affective states, I propose that in addition to this mediation model of the relationship between perceived social support, approach and avoidance motivation, and physiological and mental health, a moderation model occurs in tandem. I propose that the trait propensity to shift approach and avoidance motivation as a result of social support moderates the relationship between perceived social support and downstream benefits. This is similar conceptually to the observation that individual differences in the degree to which individuals dampen threat response when being supported corresponds with differences in regulation style (Coppola et al., 2018). I hypothesize that individual differences in the degree to which people shift their motivation when being supported will translate to differences in the degree to which they benefit from the mediation pathway described above. They will gain the benefits from social support, but only if they are responsive in shifting their approach and avoidance motivation as a result of receiving the support.

Pathways from perceived social support to physical health

Reblin and Uchino (2008) suggested two potential lines of research into the link between perceived social support and physical health. The first being the effect of social support on direct biological mechanisms of health maintenance, such as hormones and inflammatory markers, and the second being the effect on indirect behavioral mechanisms of health mechanisms, such as eating, smoking, and exercise. Each of these pathways presents a course by which the social attenuation of avoidance motivation might influence health outcomes.

Hormones and inflammatory markers

Concerning direct biological mechanisms, two of the most well researched molecular correlates of social support and physical health are the hormone cortisol and the cytokine interleukin 6 (IL-6). In one sample of 127 participants, those in the highest tertile of reported social support demonstrated a 36% reduction in basal cortisol (r^2 = .10, p = .005) compared to the lower two, even after statistically accounting for the variance due to reported stress (Rosal et al., 2004). Seeman and colleagues (1994) found a robust relationship between social support and 12-hour urinary cortisol levels in older men (Uchino et al., 1996), while Turner-Cobb (2000) and colleagues found a similar inverse relationship between diurnal salivary cortisol and perceived social support in women with metastatic breast cancer (r ranging from -.17 to -.19, depending on the form of social support [Appraisal, Belonging, and Tangible Support being significant predictors]).

Findings linking perceived social support and IL-6 have been more mixed (Reblin & Uchino, 2008). For example, while the Framingham Heart Study found that, in men, IL-6 was inversely associate with social integration after controlling for age and potential health behavioral confounds (Loucks et al., 2006), Coussons-Read and colleagues (2007) failed to find this link in pregnant women. A recent meta-analysis offers a possible explanation for this inconsistency. Smith and colleagues (2020) recently found that there was a significant, albeit small, association between loneliness and IL-6 in studies that adjusted for potential confounds (*r* = .070, 95% CI: 0.015, 0.124) but not among those with no such adjustment. This suggests the possibility that IL-6's mixed findings in the literature are driven by a lack of consistent collection and statistical methodologies.

Approach and avoidance motivation has also been linked to cortisol and IL-6, both experimentally and observationally. Cortisol administration has been shown to increases state avoidance behavior in several well-controlled experimental paradigms (Roelofs et al., 2009; van Peer et al., 2007, 2009). A recent study found that behavioral and neural measures of the ability to control shifts in approach and avoidance responses to social stimuli was inversely related to cortisol reactivity to stressor tasks (see Kaldewaij et al., 2019 for a full description of tasks and effect sizes). Similarly, a study has found that circulating levels of IL-6 was negatively correlated with frontal alpha asymmetry (FAA) (standardized β = -.156, R^2 = .021), a neural marker of approach motivation (Shields & Moons, 2016). Also, cytokines generally have been shown to be more sensitive to avoidance motivated negative emotions than approach motivated ones (Moons & Shields, 2015).

There has not been research to date examining approach and avoidance motivation as a mediator between perceived social support and hormonal or inflammatory markers of physical health. SAAT provides a framework for making predictions about the potential relationship between these three constructs. Given that the relationship between approach and avoidance motivation and the markers of physical health discussed above are bi-directional, establishing a link between perceived social support and approach and avoidance motivation could provide evidence for a two-way mediation model. Perceived social support may lower both cortisol and IL-6, as well as dampen avoidance motivation and boost approach motivation, which would in turn activate a feedback loop that enhances the attenuation of both respective outcomes.

Health promoting behaviors

Perceived social support is associated with several behaviors that promote physical health, and loneliness is associated with behaviors that hinder physical health (Reblin & Uchino, 2008). For example, qualitative studies have found that low social support was tied to decreased engagement in follow-up care among breast cancers survivors of African descent (Thompson et al., 2006) and lack of social support was identified as a challenge variable for HIV treatment patients achieving and sustaining undetectable viral loads (Alfonso et al., 2006). Further, both of these studies also found that social support, in various forms, was tied to improved prognoses for both respective groups (Alfonso et al., 2006; Thompson et al., 2006). In an observational study of French Canadian cardiovascular disease patients undergoing smoking cessation treatment, Chouinard and Robbichaud-Ekstrand (2005) found a relationship between perceived social support and continued smoking abstinence. While all participants reported receiving greater social support 2 months after treatment, at 6 months follow up abstainers reported an increase in support and smokers reported a decrease, generating a significant difference (though the study's F statistic and sample size suggests a large CI for the effect size: d = 0.39, 95% CI = 0.00, 0.79).

The extant research also indicates that increased approach motivation and decreased avoidance motivation promotes physical health maintenance behaviors. In a qualitative synthesis of help-seeking experiences for at least 20 different types of cancer from more than 775 patients and carers, Smith and colleagues (2005) identified avoidance behavior led to delayed help-seeking among individuals with cancer warning signs. Johnson and Sinatra (2014) found that while students taking a biology course did not significantly differ in terms of initial knowledge of HIV/AIDS based on avoidance goals (r = -.05), their knowledge following the course was significantly inversely correlated to their avoidance goals (r = -.18). While this difference does not necessarily predict better HIV/AIDS prevention behavior, it is not unreasonable to conclude that students with lower avoidance goals finished the biology course having better retained the knowledge necessary to perform informed HIV/AIDS prevention behaviors. Finally, a study of 465 treatment-seeking daily smokers found that smoking-specific experiential avoidance, defined as the tendency to respond inflexibly and with avoidance in the presence of smoking-related distress, mediated the relationship between trait worry and nicotine dependence, motivation to quit smoking, perceived barriers for smoking cessation, and more severe problems quitting smoking (see Farris et al., 2016 for detailed mediation effect sizes).

As with hormonal and inflammatory physiological markers, there has not been research to date as to whether perceived social support and approach and avoidance motivation represent related components of a mediated pathway to improved health promoting behaviors. While there is no evidence to support the bidirectional mediator required for the feedback loop hypothesized in the previous model for physical health, SAAT predicts perceived social support promotes healthy behavior via increases in approach motivation and decreases in avoidance motivation.

Cardiac health measures

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality worldwide (Murray & Lopez, Alan D, 1996; World Health Organization, 2020; Yusuf et al., 2001). Vagal function, as indexed by heart rate variability (HRV) HRV is strongly linked to CVD and all-cause mortality, even after correcting for traditional risk factors (Thayer et al., 2010; Thayer & Lane, 2007). High perceived social support has been significantly associated with increased (i.e., healthier) HRV in multiple samples of healthy women across the lifespan (Egizio et al., 2008; Horsten et al., 1999). Further, Gerteis and Schwedtfeger (2016) found that when individuals were in social situations, their HRV would decrease when rumination was concurrent with low perceived social support but increase when rumination was concurrent with high perceived social support (see Gerteis & Schwerdtfeger, 2016 for interaction breakdown and effect sizes).

While the extant literature is scant, there has been some preliminary data suggesting that avoidance motivation is linked to decreased HRV. Grol and Raedt (2020) found a significant association between HRV and non-affective negative switch cost (standardized β = .18), a cognitive measure inversely related to anxious avoidance. Elliot and colleagues (2011) demonstrated that participants experienced a strong decrease in HRV when shown an avoidance cue as compared to an approach cue (*d* = 1.28) or a neutral cue (*d* = 1.33). Also, one study showed that the newborns of depressed mothers had lower FAA (indicating more avoidance motivation, *d* = 0.54) and lower vagal tone (*d* = 0.50) (Jones et al., 1998).

Although there is not as much research yet into the relationship between perceived social support, approach and avoidance motivation, and cardiac health (as indexed by HRV), The initial evidence is a promising foundation to extend the predictions presented for hormone and cytokine markers and health behaviors to this domain.

Pathways from perceived social support to mental health

Several researchers have suggested a third pathway worth researching: the effect of social support on psychological factors related to physical health, such as stress, anxiety, and depression (see Uchino et al., 2012). There is strong evidence for an association between perceived social support and lower symptoms, better recovery, and higher quality of life outcomes for individuals suffering from depression and anxiety (see J. Wang et al., 2018 for a systematic review). Also, the association between depression and anxiety with increased mortality (see Cuijpers et al., 2014; Meier et al., 2016; Walker et al., 2015 for meta-analytic evidence and systematic reviews) this pathway makes sense as a target of longitudinal research.

Depression and anxiety are disorders in part defined by increased avoidance behavior and motivation. Meta-analysis has also demonstrated medium-to-strong associations between self-reported avoidant emotional regulation strategies and symptoms of depression (*r* = .48, 95% CI = .40, .55) and anxiety (*r* = .37, 95% CI = .23, .48) (Aldao et al., 2010). The relationship between depression and anxiety in relation to approach behavior is somewhat less consistent. Approach motivation negatively predicts depressive symptom severity and the chronicity of depression (Kasch et al., 2002), and positively predicts symptom improvements for depressed individuals at six month and eight month follow ups (Kasch et al., 2002; McFarland et al., 2006). The extant anxiety literature suggests a less uniform relationship between anxiety and approach motivation. Heller and colleagues (1995, 1997) suggested two anxiety subtypes characterized by different approach motivations and behaviors. Anxious arousal is the subtype of anxiety present in panic and characterized by somatic symptoms (Heller et al., 1997; Nitschke et al., 1999). Anxious arousal has repeatedly been linked to lateralized cortex activity associated with increased avoidance motivation (Burdwood et al., 2016; Engels et al., 2007, 2010; Heller et al., 1995, 1997; Nitschke et al., 1999). Anxious apprehension involves worry and is characterized by uncontrollable thoughts concerning the negative outcomes of future events (Barlow, 1991; Carter, Johnson, & Borkovec, 1986; Heller et al., 1997). This type of anxiety is central to generalized anxiety disorder, obsessive-compulsive disorder, and is frequently the anxious response measured by trait anxiety questionnaires (Heller et al., 1997). In several studies, anxious apprehension has been linked to lateralized cortex activity associated with approach motivation (Burdwood et al., 2016; Engels et al., 2007, 2010; Heller et al., 1995, 1997; Nitschke et al., 1999). Aupperle and Paulus (2010) have suggested that the conflicting over-activation of approach and avoidance related circuits might lead to the increased intolerance of uncertainty, difficulty making decisions, and tendencies towards perfectionism that are common across many anxiety disorders.

I propose that anxiety and depression play two critical roles in the relationship between perceived social support and physical health. The first is as a moderator of the change in approach and avoidance motivation as a result of receiving social support. Given that perceived social support predicts lower symptoms and faster recovery for both depressed and anxious individuals, I believe that social support will either enhance or dampen approach motivation based on the problematic pattern. I believe this will occur because of different cognitive deficiencies underlying anhedonia and anxious arousal on the one hand, and anxious apprehension on the other. In support of this conjecture, Warren and colleagues (2020) found different patterns of executive function characterized depressed mood and anxious arousal on one hand and anxious apprehension on the other. Social baseline theory predicts that individual executive functioning should become more efficient when receiving social support due to the cognitive load of threat processing being shared among the group (L. Beckes & Coan, 2011; Coan et al., 2013; Coan, Schaefer, et al., 2006). I therefore predict this increased efficiency will make up for some of the executive function deficits experience by depressed and anxious individuals, and in turn shift approach motivation towards a healthier orientation. Depressed and anxiously aroused individuals will become more approach oriented, and anxiously apprehensive individuals will become less approach oriented.

I also believe that anxiety and depression will mediate the pathway between changes in approach and avoidance motivation as a result of social support and physical health. While the majority of research has looked at either affective disorder status moderating frontal asymmetry, or vice-versa, there has been some initial evidence to suggest mediation as well. For example, Allen and colleagues (2001) found that the biofeedback training was associated with changes in affect that were mediated by changes in FAA. Participants whose neural activity was more indicative of approach motivation following the manipulation rated their affect as more positive when watching happy films than participants whose neural activity was more indicative of avoidance motivation (J. J. B. Allen et al., 2001). I believe that as approach and avoidance motivation shifts due to receiving social support, individuals are less likely to experience depression and anxiety. They are therefore less likely to experience the negative health outcomes associated with depression and anxiety. I believe this pathway will partially explain the physical health benefits of high levels of perceived social support.

Overview and Hypotheses

Social isolation and loneliness are deadly, and believing that people care and support us is critical to our well-being and physical health (Holt-Lunstad et al., 2010). By understanding why this is the case and how perceived social support conveys these benefits, we may be able to design interventions and environments that promote overall health and happiness, while decreasing the burden of loneliness. However, for us to make progress towards these innovations, research needs to develop and test theories of how perceived social support and health are related. This is why I have presented the SAAT framework, and will present analyses that translate this theoretical orientation into testable hypotheses. I believe that support from trusted individuals shifts approach and avoidance motivation in a healthier direction. I will test whether this is the case. I also predict that changes in approach and avoidance motivation as a result of social support will mediate and moderate the connection between perceived social support and health outcomes. This is because change in approach and avoidance motivation may index two, simultaneous pathways between social support and well-being. This change could measure a trait individual difference that potentiates physical responses to perceived social. It could also represent a state-driven response that represents a causal pathway between perceived social support and physical health. Figure 1 represents this theoretical framework as a basic path diagram.

To do so, I will analyze datasets that obtained neural data from participants who received social support during a threat of shock task. While social support can come in many different forms, prior research indicates that supportive touch during pain and threat of pain is a robust signal of support (L. A. Beckes et al., 2020; Reddan et al., 2020). Further, supportive touch during threat of pain has been shown to distinguish between support from a trusted partner and from a stranger, indicating that it indexes perceived support rather than operating as a simple bio-mechanical reflex (Coan, Schaefer, et al., 2006; Maresh et al., 2013).

As well as being able to fulfill many support roles, supportive touch is a particularly potent form of support to experimentally manipulate. First, touch provides a coherence between received and perceived support. While perceived social support has been shown to have several advantages, emotionally and physically, the evidence base linking positive outcomes with received social support is much more mixed (Nurullah, 2012). Therefore, it is important when selecting a social support manipulation that there be a clear association between the provided support and perceptions of being supported. Touch helps facilitate this association because there is minimum interpretation involved. Humans are, from an early age, extremely adept at perceiving social cues from touch, and distinguishing support touch from neutral touch (Björnsdotter et al., 2014; Hertenstein et al., 2006, 2009; López-Solà et al., 2019). Work from the VAN lab has demonstrated that during threat of physical pain, supportive touch's attenuation of threat processing is not mediated through the ventromedial prefrontal cortex (vmPFC), suggesting its neural effects are more direct and require less interpretation than visually aided support (L. A. Beckes et al., 2020).

Over two studies, I investigated whether holding a trusted partner's hand affected neural measures of approach and avoidance behavior. In Study 1, I did so by calculating frontal alpha asymmetry (FAA),an electroencephalographic (EEG) index of approach and avoidance motivation (Kelley et al., 2017). In Study 2, I did so by calculating laterality indexes (LIs) for two brain regions where asymmetry has been linked to approach and avoidance motivation, the amygdala and the executive control network (ECN), which contains the dorsolateral prefrontal cortex (dlPFC) (Berkman & Lieberman, 2010; Namaky, Allen, et al., 2017; Spielberg et al., 2011).

Using a neural index of approach and avoidance motivation offered several design advantages. There is a robust literature demonstrating relative left frontal cortical activity patterns are associated with approach motivation, while relative right patterns are associated with avoidance motivation (Coan & Allen, 2003b, 2003a, 2004; Kelley et al., 2017; Stewart et al., 2011, 2014). Studies examining this have included correlational associations between frontal asymmetry and trait approach and avoidance motivation (Coan & Allen, 2003b; Dawson et al., 1992; Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997) and experimental manipulations cataloging changes in frontal asymmetry following approach or avoidance-motivated emotional inductions (Davidson et al., 1990; Harmon-Jones, 2006, 2007; Harmon-Jones et al., 2002; Harmon-Jones & Sigelman, 2001). FAA is sensitive to both trait differences in approach/avoidance motivation and state manipulations of approach/avoidance motivation. There is some evidence suggesting that frontal asymmetry is sensitive to touch-based manipulation. While I have not found any previous studies that examined whether supportive touch shifts frontal asymmetry during threat of pain, there is evidence that massage therapy shifts frontal asymmetry, as indexed by EEG alpha asymmetry, left-ward in adolescents (Jones & Field, 1999) and adults (Field & Diego, 2008a, 2008b). The LI utilized for fMRI data is a method that has been well validated to examine asymmetric brain activation in fMRI (Brumer et al., 2020; Olaru et al., 2021; Seghier, 2008). Previous work has linked asymmetry in the ECN, including the dlPFC and the amygdala to both approach and avoidance motivation measured extrinsically and FAA (Namaky, Allen, et al., 2017; Namaky, Coan, et al., 2017; E. E. Smith et al., 2018; Zotev et al., 2016)

There is evidence suggesting affective disorder status can change the direction, not just the degree, of frontal asymmetry shifts. Harmon-Jones and colleagues(2008) found that individuals diagnosed with bipolar disorder, which is characterized by increased relative left frontal activity at rest and in the presence of rewards (Nusslock et al., 2012, 2015), showed an increase in relative left frontal activation when performing difficult tasks with a chance of reward, while healthy controls showed a decrease. This finding suggests that affective disorder status also a trait moderator of the relationship between emotional stimuli and frontal asymmetry in direction, when the stimuli are relevant to disorder specific behavioral and motivational patterns.

Depression and anxious arousal are characterized by more relative right frontal activity than healthy controls (Coan & Allen, 2003a, 2004; Engels et al., 2010; Grünewald et al., 2018; Nitschke et al., 1999; Stewart et al., 2010; Thibodeau et al., 2006) and anxious apprehension is characterized by more relative left frontal activity than healthy controls (Engels et al., 2007, 2010; Heller et al., 1997; E. E. Smith et al., 2016). This pattern, at least for those with a lifetime history of depression when compared to those with no history, has been shown to be more robust during emotional challenges than during resting state tasks. This increased robustness is because the degree to which depressed individuals show relative right frontal asymmetry during avoidance motivated emotional stimuli is enhanced and the degree to which they show relative left frontal asymmetry to approach motivated emotional stimuli is blunted, indicating moderation of frontal asymmetry by individual characteristics (Coan, Allen, et al., 2006; Stewart et al., 2011, 2014).

Study 1 tested whether the prediction offered in the SAAT framework, that social support shifts approach and avoidance motivation in a beneficial direction, by examining differences in FAA when individuals faced the threat of electric shock alone compared to when they received supportive touch from a romantic partner. I hypothesized that, generally, individuals receiving supportive touch would show more leftward FAA than when they completed the same task alone. This would indicate more approach orientation towards ambiguous threats when receiving social support. Additionally, I hypothesized depression symptoms, assess at the same session as the hand holding task, would be associated more rightward FAA, and so supportive touch would shift the approach motivation of these individuals in the same way. I predicted that individuals with high levels of trait anxious apprehension, again assessed during the same session as the hand holding task, would show the opposite pattern, with an overall more leftward FAA, and that supportive touch will actually decrease their approach motivation.

Study 2 aimed to test whether the predictions outlined for Study 1 held true in a separate sample, and utilize fMRI to measure whether asymmetrical activation in specific systems of the brain is affected by supportive touch. I hypothesized that individuals overall would show more leftward activations in the ECN and amygdala when holding a supportive partner's hand than when alone. I predicted again that individuals with a history of depression, this time assessed longitudinally in the 6 years prior to the fMRI scan, would show a general pattern of more rightward brain activation, which would be attenuated by supportive touch. I also predicted the opposite pattern for individuals with a history of anxiety.

Study 2 also examined whether the degree to which individuals' neural signals differ as a result of supportive touch moderated and/or mediated the relationship between perceived social support and well being outcomes. In order to use changes in the neural signal as an index of both a trait-like moderating variable and a state-dependent mediating variable, Study 2 utilized the method and conceptualization outlined by Karazsia and Berlin (2018) for using a variable as both a mediator and moderator within The MacArthur approach to third variables. The MacArthur approach to third variables specifies that a true moderator must precede the variables whose relationship it is augmenting (Kraemer et al., 2008). However, a mediating variable must come chronologically between the two variables whose relationship it causally linking (Karazsia & Berlin, 2018; Kraemer et al., 2008). With this approach to mediation and moderation, it is therefore theoretically impossible for a variable to mediate and moderate the same temporal relationship simultaneously, due to chronological constraints (Kraemer et al., 2008). Such an analysis is mathematically possible in a structural equation modeling (SEM) or regression framework (A. Hayes, 2017; A. F. Hayes, 2018). However, this would represent only statistical mediation and moderation, not mechanistic or theoretical. When using longitudinal data, a variable could be used to index state-dependent changes in a mediation model and also as a preexisting individual difference in a different moderation model, as long as the variables measured by the respective models follow the chronology required by the MacArthur approach (Karazsia & Berlin, 2018).

Study 2 used this framework to test my hypothesis that changes in approach and avoidance motivation as a result of social support would moderate and mediate the relationship between perceived social support and physical health. I predicted that a change in approach and avoidance motivation linked to social support, which I operationalize as the difference in LI scores between the partner and alone conditions of the hand holding task, would moderate the relationship between perceived social support assessed before the fMRI scan and physical health outcomes assessed afterward. I also hypothesized that the difference in LI between conditions would significantly mediate the relationship between perceived social support and physical health outcomes, both assessed after the fMRI scan. I predicted that individuals with high levels of social support would have healthier cardiac activity, lower cytokine levels, and engage in less drinking and drug use if they demonstrated relatively greater differences in LI. Figure 2 represents the measures used and their chronology in the SEM models testing these predictions.

Finally, Study 2 tested if depression and anxiety in the years following the scan would mediate the relationship between the difference in LI between conditions and later health outcomes. As outlined above, Study 2 will test whether anxiety and depression symptoms measured before the scan moderate the relationship between supportive touch and the difference in LI between conditions. As with changes in approach and avoidance motivation due to social support, depression and anxiety measure could represent both a trait individual difference as well as state reactions to changes in approach and avoidance motivation. I hypothesized that depression and anxiety measures obtained after the fMRI scan in Study 2 would mediate the relationship between differences in LI related to social support and physical health outcomes, while measures obtained before the scan would moderate the relationship between perceived social support and LI differences. I predicted that smaller differences in LI between conditions would be associated with greater depression and anxiety after the scan, which would in turn be associated with worse physical health. I also predicted that higher depression and anxiety before the scan would be associated with a weaker link between perceived social support and motivational reactivity. Study 2 tested this utilizing path model framework, represented by Figure 3.

Methods

Study 1

Participants and recruitment

Dyads of romantic partners (dyads = 101, total participants = 204) were recruited through the University's participant pool. In order to participate, dyads had to be in a romantic relationship for at least 3 months, and be willing to attend a laboratory session at the same time. Participants were screened over email to verify the length of their relationship and ability to comply with study procedure. Participants were excluded if they had a history of neurological disorder. Both members of the dyad filled out a number of self-report measures. For the purpose of the hand holding task (details below), one member of the dyad was considered the "participant", and the other the "supporting partner". For this dissertation, because the EEG data from the hand holding task was used, only the participants data was utilized. Of the dyad members designated the participant, the mean age was 19.36 years old (*SD* = 1.00, range = 18 - 22). Participants reported their race as White (*n* = 71, 70.30%), Asian (*n* = 16, 15.84%), Black/African American (*n* = 7, 6.93%), multiple races (*n* = 4, 3.96%), and non-disclose (*n* = 3, 2.97%). 8 participants (7.92%) self-identified as Hispanic or Latino. Self-reported sex included female (*n* = 66, 65.35%) and male (*n* = 34, 33.66%).

Participants' data were excluded from analyses if their EEG data could not be used to calculate an FAA score from both the partner and alone conditions. This yielded a sample of 74 participants whose data were used in analyses. This sample reported a mean age of 19.45 years old (*SD* = 0.96, range = 18 – 22). Self reported race included White (*n* = 54, 72.97%), Asian (*n* = 12, 16.21%), Black (*n* = 4, 5.41%), multiple race (*n* = 1, 1.35%), and non-disclose (*n* = 3, 4.05%). 6 of the remaining participants self-identified as Hispanic or Latino (8.11%). Self-reported sex in the remaining sample included female (*n* = 50, 67.57%) and male (*n* = 24, 32.43%).

Materials

Trait Measures

A Demographic Questionnaire was used to used to assess a variety of variables. Self-reported sex, age, race, and ethnicity were evaluated for this dissertation.

Psychopathology Measures

Beck's Depression Inventory – II (BDI-II; Beck et al., 1996): a 21 item multiple choice self-report measure assessing symptoms of depression. Items measuring both the affective and physical components of depression are rated on a scale of 0 – 3, with higher scores indicating more severe symptomatology. Previous psychometric testing has estimated internal consistency to be .90 (Cronbach's α) and test-retest reliability ranging between .73 - .96 (also α) (Y. P. Wang & Gorenstein, 2013). For Study 1, I utilized the total BDI-II score. The current sample had a mean of 5.489 (*SD* = 4.93). 10 participants (13.51%) obtained BDI-II scores greater than 14, the accepted cutoff for clinically relevant depressive symptoms (Beck et al., 1996).

State Trait Anxiety Inventory – Trait (STAI-T; Spielberger et al., 1970): a 20 item self-report measure assessing trait anxiety. Items are rated on a 1-4 scale, with higher ratings indicating more severe anxiety symptoms. Previous psychometric testing has estimated internal consistency to be between .86 - .95 (Cronbach's α) and test-retest reliability ranging between .65 - .75 (also α) (Spielberger, 1989). The STAI-T has previously been used extensively as a measure of anxious apprehension (Heller et al., 1997; Nitschke et al., 1999; E. E. Smith et al., 2016). For Study 1, I utilized the total STAI-T score. The current sample had a mean of 47.08 (*SD* = 3.53). 51 participants (68.92%) obtained STAI-T scores greater than 45.5, the accepted cutoff for clinically relevant trait anxiety symptoms (Stojanović et al., 2020).

Procedure

After being screened, dyads were invited to the research facility at the University of Virginia where they consented to the study. One member of the dyad was designated the “participant,” while the other was the “partner.” Following the completion of a questionnaire battery, including the BDI-II and STAI-T, the participant was fitted with an EEG cap and two Ag-AgCL shock electrodes. Electrodes were applied to the participant and partner’s ankle (left or right was counterbalanced across dyads). The participant was seated in a sound attenuated EEG chamber and white noise was used to further lower auditory pollution. The partner sat on the other side of a heavy curtain from the participant, controlling for the effects of any supportive behaviors other than hand holding. The participant and partner could not see each other and were instructed not to speak during the hand holding task. After being seated, shocks were calibrated for each participant and partner. Starting with the lower setting (0.1 milliAmps), current was increased and the participant and partner were respectively asked if the shock was painful. Current was increased individually for the participant and partner until they reported the shock was painful, or until the highest setting (4.0 milliAmps) was reached.

Participants and partners underwent the hand holding task in five blocks, during which either the participant, the partner, or a supporting stranger was under threat of electric shock. This yields one condition when the participant is alone and under threat of shock, two when the participant is being supported by someone else while under threat of shock (the partner in one condition and a stranger in the other), and two conditions when the participant offered support to someone else under threat of shock (the partner in one condition and a stranger in the other). Because this dissertation examined the neural response of receiving support, only conditions where the participant was under threat of shock were evaluated. Also, because the aims of this study concern support from trusted individuals, only conditions where the participant was alone or with their romantic partner were considered. Thus, two conditions were analyzed, when the participant was alone and threatened by shock, and when the participant was supported by their partner and threatened by shock.

Study instructions were administered using PsychoPy2 (Peirce et al., 2019) on a single computer screen visible to both the participant and the partner. A blue “O” on the screen indicated that there was no threat of shock to the participant (safety cue). A red “X” indicated a 20% chance that the shock previously calibrated to the participant would be administered (threat cue). 24 threat and 24 safety cues were administered in a random order. Cue presentation lasted for 1 second, followed by a 4 second waiting period. After the 4 second period, a 1 second cue indicated the end of the trial. During this end of trial cue, on exactly 20% of the trials following the shock cue, a 500 millisecond mild shock was delivered. All shocks were computer controlled and automatically generated by an isolated physiological stimulator. Following the hand holding paradigm, participants and their partners were debriefed.

EEG Recording and Processing

Tin electrodes in a 32-channel stretch-lycra cap were used to record EEG at sites FP1, FP2, F7, F8, F3, F4, Fz, FT7, FT8, FC3, FC4, FCz, T7, T8, C3, C4, Cz, TP7, TP8, CP3, CP4, CPz, P7, P8, P3, P4, Pz, O1, O2, & Oz. All sites were acquired with an online reference site immediately posterior to Cz and referenced offline to the averaged mastoids (LM). Four electrodes channels were used to monitor electrooculogram (EOG) activity for eye movements, with one electrode placed below the left eye at approximately 10% of the nasion-inion distance in line with the pupil, another placed directly above the left eyebrow, and two other electrodes placed on the outer canthi, also in line with the pupil. Preprocessing was conducted using EEGLAB, a MATLAB plug in that is free to use (Delorme & Makeig, 2004). Following the procedure recommended by Delorme and Makeing (2004), a 1-50Hz band-pass filter was first applied in order to remove low frequency noise and gradient artifacts. EEG data was then segmented into epochs consisting of 500 ms before the threat or safety cue, and 4000 ms following cue onset. Individual component analysis (ICA) was then performed on these epochs, and these components were examined and rejected based on visual inspection and the semi-automated procedure MARA in EEGLAB. Following this, epochs were visually inspected and selected for data rejection. ICA was then performed a second time, and components were visually inspected again for rejection.

Because the analysis in this dissertation is specifically concerned with data acquired from frontal electrodes, participants were not used if channels F3 and/or F4 were deemed too noisy following the cleaning procedure by myself and a trained research assistant. This initial cut yielded the 74 participants used in subsequent analyses. Following artifact removal and rejection, an average of 36 out of 48 trials were retained for each condition. For condition by cue, retained trials were: alone and safe condition (M = 18.97, SD = 3.56, range = 13 – 24), alone and threat condition (M = 19.27, SD = 3.35, range = 15 – 24), partner and safe condition (M = 19.50, SD = 2.67, range = 17 – 24), and partner and threat condition (M = 18.98, SD = 2.71, range = 15 – 22). The number of trials did not differ significantly between conditions nor cues, all $p > 0.10$.

Following artifact rejection, FAA scores were obtained using the method described by Smith and colleagues (2017). Total power was determined by tapering epochs with a 500ms overlapping Hamming window and applying a fast-Fourier transform (FFT) to the power spectra. At F3 and F4, total alpha power (8 – 13 Hz) was extracted. An FAA score was obtained by subtracting natural-log transformed alpha at left frontal leads from the natural-log transformed alpha at homologous right front leads ,i.e., ln(F4) − ln(F3). The F3/F4 pair was chosen because because they correspond to the regions most commonly studied in frontal asymmetry studies (J. J. B. Allen et al., 2004; Horato et al., 2022). Due to the inverse relationship between alpha power and neural activity, higher FAA indicates more left frontal activity. FAA and alpha power were calculated separately for each condition and each cue.

Analysis

I conducted statistical analyses for Study 1 using R (R Core Team, 2020) and the package lme4 (Bates et al., n.d.) implemented with RStudio (RStudio Team, 2019). I first fit a series of simple linear regressions to examine if BDI-II or STAI-T scores differed based on reported sex, race, ethnicity, or age. None of these demographic variables significantly predicted BDI-II or STAI-T scores, and so were not included in subsequent analyses. I fit Hierarchical linear models with condition (alone vs. partner), cue (threat vs. safety), STAI-T score, and BDI-II score entered as independent variables. My dependent variables were FAA obtained from the F3/F4 pair, alpha power at the two leads. This was done in order to examine whether differences in FAA were due to changes across both leads, or lateralized changes (see Hecht, 2010 for a systematic review of the roles of the left and right hemisphere in proccesses relevant to depression). I fit the models' fixed effects' structure in a step-wise fashion, fitting all independent variables as main effects simultaneously, followed by all two-way interactions, then all three-way interactions, and finally the full four way interaction. I also fitted a random intercept for each participant. All *p*-values were adjusted for multiple comparisons by controlling for the false discovery rate using the method outlined by Bejamini-Hochberg method (Srinivasan et al., 2013) implemented with the p.adjust function in R.

Results

Contrary to my hypotheses, no significant main effects or interactions were found in the model for FAA or the model for F4 alpha power. The model for F3 alpha power yielded a significant condition by STAI-T by BDI-II interaction (std. β = .17, adjusted p = .010) and a significant main effect of cue (std. β = .20, adjusted p = .004) (see Table 1 for the full model parameters and effects of the F3 model). The main effect for cue indicates an increase in F3 alpha power when participants viewed threat cues compared to when they viewed safety cues. Participants did exhibit less left frontal activity when viewing threat cues, as predicted, however this change was not observed in the FAA index.

In order to characterize the three-way interaction between condition, STAI-T, and BDI-II, subsequent hierarchical linear models were fitted for the alone and partner conditions separately. Following the same structure as the models outlined above, these models included cue as a first level covariate, STAI-T and BDI-II as main effects, and the two-way interaction of STAI-T and BDI-II. P-values reported for these follow up models are not adjusted, given they were used to characterize the effect from the main model, and were not utilized for hypothesis testing. In the alone condition, there was no significant effect of STAI-T, BDI-II, or their interaction. In the partner condition, the interaction term was significant (std. $\beta = .25$, $p = .029$). This two way interaction was plotted and examined following the procedure outlined by Aiken and West (1991). This plotting revealed that the predicted effect of high depression symptoms was found, with decreased left frontal activity compared to individuals with low depression symptoms. However, this effect occurred only in the partner condition, and only for individuals also high in anxious apprehension. See Figure 4 for a plot of this effect.

Study 2

Participants and recruitment

Participants in Study 2 were a subset of a community sample recruited by the KLIFF/VIDA project. The KLIFF/VIDA project has been assessing participants annually for over a decade, starting in seventh or eighth grade (mean age = 13.3 years) until the latest round of collection, with participants now 31 years of age. The subsample for the analyses Study 2 consists of 86 individuals from the sample who came in for an additional session of data collection that included performing several tasks while fMRI was collected (Coan et al., 2017). Participants were instructed to bring an opposite-sex partner to complete an fMRI version of the hand holding threat task described in study 1. Within these dyads, 27 identified as friends, 29 identified as non-cohabiting romantic partners, 27 identified as cohabiting romantic partners, and 3 identified as married. Study 2 utilized data from an fMRI version of the hand holding task, as well as self-report measures taken annually as part of the KLIFF/VIDA project and in conjunction with the extra scanning session.

Of the 86 participants who came in from scanning, 72 had neural data that was sufficiently motion free to include in this dissertation's analyses. Within these dyads, 23 identified as friends, 25 identified as non-cohabiting romantic partners, 23 identified as cohabiting romantic partners, and 1 identified as married. Because analyses including interaction terms with relationship type could not include a group with only one datapoint, this dyad was dropped from analyses, yielding a final sample of 71 participants and their partners. Of note, because romantic partners in the sample were all members of heterosexual dyads (i.e., male/female pairs), participants who brought a friend for the study were asked to bring an opposite sex friend. Among the 71 participants included in this dissertation's analyses, 39 self-identified as female (54.93%) and 32 self identified as male (45.07%). Participants reported their race as White (*n* = 40, 56.34%), Asian (*n* = 25, 35.21%), Hispanic (*n* = 2, 2.82%), and other (*n* = 1, 1.41%).

Materials

Trait measures.

Participants and partners filled out a demographic questionnaire and self-reported sex, age, race, and ethnicity were evaluated for this dissertation.

Psychopathology measures

Beck's Depression Inventory – II (BDI-II; Beck et al., 1996): The BDI-II was also used in Study 2 to characterize participant's depressive symptoms. The BDI-II was collected from each participant annually, starting when they were 16 years old. For Study 2, the BDI-II was used from three measures of depressive symptoms. Mean BDI-II scores from the years before the scan (pre-BDI) and mean BDI-II scores from the years following the scan (post-BDI) were calculated as a continuous measure of participant's experiences of depressive symptoms. Also, participants' BDI-II scores from before the scan were examined, and participants who reported any time period with a BDI-II score of 14 or higher were considered to have had a history of a major depressive episode. This additional use of the BDI-II to characterize participants as either having or not having a major depressive episode in the past was based on previous work showing that neural asymmetry measures are more strongly associated with whether or not individuals have a history of major depression than with continuous measures of depressive symptoms (E. E. Smith et al., 2017) The current sample had a pre-BDI mean of 4.83 (*SD* = 3.98) and a post-BDI mean of 5.47 (*SD* = 4.72). 22 participants (30.96%) were categorized as having a history of a major depressive episode.

State Trait Anxiety Inventory – Trait (STAI-T; Spielberger et al., 1970): The STAI-T was also used in Study 2 to index participants' anxious apprehension symptoms. The STAI-T was also assessed annually starting when participants turned 18 years old. Mean STAI-T scores from the years before the scan (pre-STAI) and mean STAI-T scores from the years following the scan (post-STAI) were calculated as a continuous measure of participant's experiences of anxious symptoms. Participants' STAI-T in the years before the scan were examined, and participants who reported any time period with an STAI-T score of greater than 45.5 were considered to have a history of a clinically significant anxious episode. The current sample had a pre-STAI mean of 35.84 (*SD* = 7.35) and a post-STAI mean of 33.87 (*SD* = 8.39). 47 participants (66.20%) were categorized as having a history of a major anxious episode.

Perceived social support measures

Multidimensional Scale of Perceived Social Support (MSPSS; Zimet et al., 1988): a 12-item questionnaire which measures perceived support from family, friends and significant others. Items are presented with a seven-point Likert scale (1 = very strongly disagree; 7 = very strongly agree), with higher scores indicating a higher level of perceived support. Previous psychometric testing reports an internal consistency estimated to be .88 (Cronbach's α) for the total scale and test–retest reliability estimated at ~.85 (also α) (Zimet et al., 1988). Total scale scores were used, rather than the individual support source subscores. MSPSS was assessed shortly before the fMRI tasks during the additional session (participants were aged 23).

Social Support Questionnaire (Sarason et al., 1987): The SSQ is a 27-item questionnaire that measures the availability of and satisfaction with social support. For the KLIFF-VIDA study, participants were given a shortened form consisting of 6 items, which has been previously validated through an extensive factor analysis (Sarason et al., 1987). Items were presented with a six-point Likert scale (1 = very dissatisfied; 6 = very satisfied) with higher scores indicating more available and more satisfying social support. Participants scores on the SSQ were acquired every year following the fMRI scan, and average for these analyses.

Physical Health Measures

IL-6: Circulating concentrations of IL-6 were calculated from a 20mg draw of blood at age 29 and age 30. In line with typical procedure for measures of IL-6 concentration, scores were then log-transformed to address skewness (see J. P. Allen et al., 2018 for additional information on IL-6 procedure). The average IL-6 concentration of the two blood draws was used for these analyses.

Resting Heart Rate Variability (HRV): Heart rate data was collected via electrocardiogram (EKG) while participants rested in a comfortable chair and watched a soothing outdoors video for ten minutes at age 29 and age 30. HRV was calculated using root mean square of successive differences (RMSSD), because this measure corresponds strongly with vagal tone and is therefore of theoretical interest (Laborde et al., 2017). The average of the two EKG sessions was used for these analyses.

Body Mass Index (BMI): BMI was calculated at age 29 and age 30 using the standard formula (i.e., kg/m^2). BMI was used in this study due to its strong association with mortality in the overweight range (Lewis et al., 2009). The average of the two BMI assessment was used for these analyses.

General health: Following the method employed by Allen and colleagues (2015), who have previously assessed determinants of overall physical health in this sample, general physical health was assessed using the five-item, self-report general-health scale from the Medical Outcomes Study Short-Form Health Survey (Ware et al., 1993). The scale utilizes Likert-type questions assessing overall health and yields scores of 0 – 25, with higher scores indicating better overall health (J. P. Allen et al., 2015). Scores following the scan were averaged for these analyses.

Health-related behavior measures

Monitoring the future survey (Johnston et al., 2019): Alcohol, and hard drug use was assessed using the total number of instances of use in the 12 months prior to survey administration. Participants reported use of various legal and illegal drugs on a scale ranging from 1 (none) to 5 (10 or more times). Participants completed the survey annually from ages 25 – 29, and the results for each class of drug were averaged across that time period, following the procedure outlined by Allen et al (2015). For this averaging, the total score for eight hard drug categories (hallucinogens, barbiturates, tranquilizers, amphetamines, inhalants, heroin, cocaine, and oxycontin) was used as an annual hard drug use score. An annual alcohol use score was the single item assessing the number of binge drinking episodes over the 12 months prior to survey. Averages for hard drug use and alcohol use after the scan were used for these analyses.

Procedure

Participants were screened via telephone and were excluded at screening if they had a medical condition that precluded scanning via MRI. Participants came with their partner, and both completed a battery of questionnaires assessing demographics, personality, attachment style, relationship measures, and other variables. For Study, questionnaire data about perceived social support taken before the scan was used, as well as measures participants filled out in the years prior to and following the scan as part of the larger KLIFF/VIDA study.

Participants completed the hand holding task outlined in Study 1, with some notable differences. During this data collection, the member of the dyad that was participating in the larger KLIFF/VIDA study was always considered the participant, and the partner was never scanned. Also, this version of the hand holding study only featured threat of shock to the participant, and never the accompanying partner or stranger. Participants viewed the cues projected onto a screen at the back of the MRI magnet’s bore via a mirror placed on the head coil. During each condition of the hand holding paradigm, participants observed 12 threat and 12 safety cues, and participants were informed there was a 17% chance of being shocked. Participants also did not undergo the calibration procedure that was used in the EEG version of the paradigm, and all received a uniform 4 miliAmp shock. The timing of cues was also adjusted to account for the differential required of BOLD signal processing compared to EEG analysis. The threat or safety cue was presented for 1 second, followed by a jittered fixation cue (a small dot) that was presented for 4, 6, 8, or 10 seconds. Following a fixation cue, the end cue was shown for 1 second, and on 17% of threat trials electric shock was administered at the beginning of the end cue. Following the end cue, participants were shown a blank screen for a jittered rest period of either 4, 6, 8, or 10 seconds.

fMRI acquisition and processing

Images were acquired using a Siemens 3.0 Tesla MAGNETOM Trio high-speed magnetic imaging device with a CP transmit/receive head coil and integrated mirror. One hundred seventy-six high-resolution T1-magnetization-prepared rapid-acquisition gradient echo slices were collected to determine the localization of function (1-mm slices, TR = 1900 ms, TE = 2.53 ms, flip angle = 9°, FOV = 250 mm, voxel size = 1 × 1 × 1 mm). Two hundred sixteen functional T2*-weighted Echo Planar images (EPIs) sensitive to BOLD contrast were collected per block, in volumes of twenty-eight 3.5-mm transversal echo-planar slices (1-mm slice gap) covering the whole brain (1-mm slice gap, TR = 2000 ms, TE = 40 ms, flip angle = 90°, FOV = 192 mm, matrix = 64 × 64, voxel size = 3 × 3 × 3.5 mm).

Data was preprocessed using FMRIB's Software Library (FSL) software (Version 5.98; www.fmrib.ox.ac.uk/fsl). Motion was corrected using FMRIB's Linear Image Registration Tool, an intra-modal correction algorithm tool (MCFLIRT; Jenkinson et al., 2002). Slice scan-time correction was performed and a high-pass filtering cutoff point of 100s, removing signals that were irrelevant to the stimuli. BET (Smith, 2002) was used for brain extraction, which eliminated unwanted, non-brain material voxels in the fMRI data, and conducted spatial smoothing with a 5-mm full width at half minimum Gaussian kernel. Images were registered to the Montreal Neurological Institute (MNI) standard space by FLIRT (Jenkinson et al., 2002). Threat trials where participants actually received shocks were excluded from analysis due to possible movement artifacts.

Data analysis was conducted using FEAT (fMRI Expert Analysis Tool) Version 5.98 in the FSL package. For first level analysis, in order to compare the neural response to threat of shock, threat minus safety maps were created by subtracting the response to the safety cue from the response to the threat cue for each handholding condition. For second level analysis, these data were collapsed across all three functional runs, one for each handholding condition, for each individual participant using a fixed effects model. Only the partner support and alone conditions were used in this study, as outlined in Study 1. Rather than continuing onto third level analyses by including covariates of interest in a GLM throught FEAT, a laterality index (LI) was calculated for each participant from each condition.

Laterality index (LI)

Following the procedure outline by Ito and Liew (Ito & Liew, 2016)LIs were calculated for the amygdala and ECN for each participant for both the alone and partner support conditions. LI has been used to characterize hemispheric dominance in specific ROIs across a variety of fMRI tasks, and represent a functional analog to the FAA scores used in Study 1 (Ito & Liew, 2016) First, masks were created for the ECN and amygdala separately, utilizing brain atlases well-validated for task-related fMRI analysis (Shirer et al., 2012). The LI was then calculated per participant, based on the number of active voxels within each mask across a range of Z-value thresholds ($z = 1.0$, $z = 1.5$, $z = 2.3$). The total number of active values at each threshold was calculated for both ROIs in each hemisphere, and the LI was calculated for each region with the formula LI = (Left active voxels – Right active Voxels)/(Left active voxels + Right active Voxels) for each threshold. These LIs were averaged together, and used for the analyses in this dissertation. This generates ranging from -1 to 1, where positive values indicate left-hemisphere dominance, and negative values indicate right-hemisphere dominance (Ito & Liew, 2016).

Analysis

I conducted statistical analyses for Study 2 using R (R Core Team, 2020) and the packages lme4 (Bates et al., n.d.) and lavaan(Rosseel) implemented with RStudio (RStudio Team, 2019). I first fit a series of simple linear regressions to examine if pre-BDI, post-BDI, history of depressive episodes, pre-STAI, post-STAI or history of anxious episodes differed based on race, or age. None of these demographic variables significantly predicted psychopathology, and so were not included in subsequent models.

I fit Hierarchical linear models with condition (alone vs. partner), relationship type (friend vs. non-cohabiting romantic vs cohabiting-romantic), and measures of historic psychopathology as independent variables. Given that history of major depressive episodes and history of anxious episodes could not be entered into models with interactions due to causing rank deficient matrixes in this sample, I fit models separately for these two measures, with each psychopathology model including the other measurement only as a first degree covariate. This rank deficiency was not present when modeling the interactions of pre-BDI and pre-STAI, and so these measures and their interactions were included in the same models. My dependent variables were the LI for the ECN and the LI for the amygdala in separate hierarchical linear models.

This led to a total of 6 hierarchical linear models to test the hypotheses concerning the effect of supportive touch on frontal asymmetry and the moderating effect of psychopathology history: ECN LI predicted by condition, relationship status, and history of major depressive episodes (with history of major anxious episodes included as a covariate), amygdala LI predicted by condition, relationship status, and history of major depressive episodes (with history of major anxious episodes included as a covariate), ECN LI predicted by condition, relationship status, and history of major anxious episodes (with history of major depressive episodes included as a covariate), amygdala LI predicted by condition, relationship status, and history of major anxious episodes (with history of major depressive episodes included as a covariate), ECN LI predicted by condition, relationship status, pre-BDI and pre-STAI, and amygdala LI predicted by condition, relationship status, pre-BDI and pre-STAI.

I fit the models' fixed effects' structure in a step-wise fashion, fitting all independent variables as main effects simultaneously, followed by all two-way interactions, then all three-way interactions for the models including histories of major episodes. The models including both pre-BDI and pre-STAI also included the full four way interaction. I also fitted a random intercept for each participant. All *p*-values were adjusted for multiple comparisons by controlling for the false discovery rate using the method outlined by Bejamini-Hochberg method (Srinivasan et al., 2013) implemented with the p.adjust function in R.

To examine whether or not changes in approach and avoidance motivation due to social support moderates and/or mediates the relationship between perceived social support and the measures of physical health outlined above, I fit the path models shown in Figure 2 using lavaan (Rosseel, 2012). I operationalized the change in approach and avoidance motivation as the difference between LI for the partner and long conditions of each ROI. For the moderation models, I utilized the average SSQ as my measure of perceived social support, each of the health and behavioral measures as my predicted variables and the difference between LI for the partner and alone conditions of each ROI as my moderator variable. For the mediation models, I utilized the pre-scan MSPSS as my measure of perceived social support, each of the health and behavioral measures as my predicted variables, and the difference between LI for the partner and alone conditions of each ROI as my mediator. In order to account for the chance of spurious findings, given the number of models ran, the number of significant paths was compared against the expected number of significant paths given a binomial probability at alpha = .05.

To test whether depression and anxiety mediated the pathway between motivational reactivity and physical health outcomes, I fit the path model outlined in Figure 3 using lavaan. I used MSPSS as my measure of perceived social support, pre-BDI and pre-STAI as the measures of psychopathology moderating the pathway between perceived social support the difference between LI between conditions of each ROI, post-BDI and post-STAI as the measures of psychopathology mediating the relationship between difference in LI and physical health outcomes, and each of the physical health and behavioral measures outlined above as the indexes of physical health. In order to account for the chance of spurious findings, given the number of models ran, the number of significant paths was compared against the expected number of significant paths given a binomial probability at alpha = .05.

Results

All six of the hierarchical linear models indicated a significant, positive effect of condition and a significant negative intercept. The negative intercept indicates that participants were more right-dominant in the ECN and amygdala when looking at threat cues that when looking at safety cues. The direction of the condition effect indicated that participants were more left hemisphere dominant in the amygdala and ECN when being supported by their partners than when alone. No other effects were found in any of the models predicting the ECN LI.

In the models predicting the amygdala LI from major depressive and major anxious episodes, there was also a significant main effect of a history of major anxious episodes (std. β = 0.23, adjusted p = 0.038) and major depressive episodes (std. β = -0.50, adjusted p = 0.042). The direction of this effect indicated that individuals with a history of major anxious episodes were more left amygdala dominant than those without a history of major anxious episodes, and individuals with a history of major depressive episodes were more right amygdala dominant when than those without a history of major depressive disorders. The main effect of pre-STAI was not significant in the model utilizing pre-STAI and pre-BDI to predict amygdala LI. See Figures 5 and 6 for the significant main effects of the models predicting amygdala LI. Summary tables of the main effects level of all 6 hierarchical linear models are included in the supplementary materials. See Table 2 for the summary of main effects in the models predicting the LI obtained from the amygdala.

A significant three way-interaction of a history of major depressive episodes, relationship type, and condition was found in the model predicting the amygdala LI (std. β = -2.21, adjusted p = 0.020. To examine this interaction, hierarchical linear models were fit separately for each relationship type to see if there was a significant interaction between condition and a history of major depressive episodes when predicting the amygdala LI. *P*-values from these models were not adjusted for multiple testing, because they were utilized to understand the interaction from the overall model and therefore not used directly for hypothesis testing. There was no significant effect of a history of major depressive episodes or the interaction between history of major depressive episodes for participants whose supportive partner was a friend.

Among participants whose supportive partner was a non-cohabiting romantic partner, there was no significant interaction between condition and a history of major depressive episodes. There was a significant main effect of major depressive episode in this model (std. $\beta = -0.81$, $p = 0.016$), such that participants with a history of major depressive episodes showed greater right hemispheric dominance in the amygdala than those with no history of major depressive episodes. See Figure 7 for a visualization of this effect.

There was a significant interaction effect between condition and history of major depressive episodes among participants whose supportive partner was a cohabiting romantic partner (std. $\beta = -1.54$, $p = 0.005$). Separate simple linear models were run to determine whether there was a significant main effect of condition for individual with and without a history of major depressive episodes whose supportive partner was a cohabiting romantic partner. The model for individuals without a history of major depressive episodes included a significant effect of condition in the direction outlined above (std. $\beta = 0.27$, $p = 0.023$). The model for individuals with a history of major depressive episodes did not include a significant main effect for condition, indicating that these individuals' neural reaction to the threat cue was not ameliorated by the presence of their supportive partner. See Figure 8 for a visualization of the difference in these effects.

None of the path models fitted to test moderation or mediation effects indicated significant effects of LI difference. This was largely due to the lack of a relationship between the measures of perceived social support and physical health outcomes. The relationship between hard drug use and SSQ was the only significant prediction based on a measure of perceived social support in any of the models.

Conclusions

Findings were mixed with regards to supporting the hypotheses I generated using the SAAT framework. Analysis of the LI of the amygdala and ECN in Study 2 generally supported the hypothesis that social support shifts individuals into a more approach oriented motivation. All models of LI for both ROIs indicated that participants in Study 2 were more left-dominant during the partner condition than during the alone condition. However, neither FAA nor F4 alpha power showed any reactivity to supportive touch in Study 1.

When considering my hypothesis that depression and anxiety would moderate the neural reactivity to social support during threat, I again found mixed results. In Study 1, I found that alpha power at F3, the left frontal region, was reactive to condition. However, this was only the case for individual high in both anxious apprehension and depression symptoms. Therefore, I did not have a prediction for this group, as this interaction term was exploratory. The direction of the change, indicating a decrease in left frontal brain activity when receiving supportive touch, is in the direction I predicted for individuals high in anxious apprehension, but the opposite direction of the one predicted for those with more severe depressive symptoms. Also, this effect was only observed for F3 alpha power, and not for FAA or F4 alpha power.

The moderating effect of psychopathology on changes in approach and avoidance motivation in Study 2 were also mixed. No effects of psychopathology were found when examining the mean of depressive and anxious symptoms assessed in the years leading up to the scanning session. When assessing psychopathology more categorically, by classifying participants as either having a history of major depressive and/or anxious episodes or not, psychopathology was shown to have an effect on approach motivation only when indexed by the amygdala LI. Participants with a history of major anxious episodes showed a greater approach orientation, and participants with a history of major depressive disorders showed a greater avoidance orientation, as predicted. Participants with a history of major depressive episodes who brought a non-cohabiting romantic partner to be their supportive partner showed a more right-dominant amygdala LI, in line with the prediction that individuals with a trait propensity for depression would generally be more avoidance motivated (or less approach motivated) This effect was not ameliorated by the presence of their supportive partners. Participants with a history of major depressive episodes also did not show changes to approach motivation when supported by a cohabiting romantic partner, but individuals without a history of major depressive episodes did. This potentially indicates that trait depression may blunt individuals' ability to utilize trusted individuals to shift approach and avoidance motivation in helpful directions, depending on the context. In conclusion, when approach and avoidance motivation was found to be related to anxiety or depression, the main effects of psychopathology were in the expected directions. However, unlike I predicted, supportive touch did not dampen the effects of psychopathology. Rather, psychopathology dampened the effects of state social support.

Study 2 did not offer any support for the pathways I proposed explaining the relationship between perceived social support and physical or mental health outcomes. This was due to the fact that, by and large, there were no relationships to explain. Perceived social support, as I indexed it in this dissertation, was not associated with physical or mental health outcomes assessed longitudinally following participants' fMRI scan.

Discussion

The primary goal of this dissertation was to test hypotheses generated using a newly proposed theoretical framework, Social Augmentation of Approach/Avoidance Theory (SAAT). First I investigated whether social support, in the form of supportive touch, shifted individuals into a more approach motivated state, as indexed using FAA in one sample and LIs obtained from the ECN and the amygdala in another. I then utilized these neural indexes to examine if anxiety and depression were associated with greater approach and greater avoidance motivation, respectively, in response to threats. I followed this by testing whether anxiety and depression moderated the effect of social support on these neural indexes by changing the direction of the shift in approach and avoidance motivation, which I predicted they would. I then tested whether changes in neural indexes of approach and avoidance motivation represented trait-dependent moderators or state-dependent mediators of the relationship between perceived social support and subsequent measures of physical health.

To test these hypotheses, I analyzed previously collected datasets of participants who underwent a task during which they experienced the threat of shock either while holding a supportive partner's hand or while alone. In Study 1, I examined a dataset which was collected from 74 individuals completing this task either alone or with a romantic partner. I calculated FAA, an index of approach and avoidance motivation, as well as the power spectra (alpha power) contributing to FAA from F3 (left frontal) and F4 (right frontal) leads. The effects of the task were isolated to the F3 lead, and neither different cues nor differential support elicited changes in FAA or F4 alpha power. F3 alpha was shifted in the expected direction by different cues. Participants showed decreased left frontal activity, associated with greater avoidance motivation, when presented with threat cues than when presented with safety cues. Individuals in Study 1 with high levels of both depressive symptoms and trait anxiety showed decreased left frontal activity when supported by their romantic partners than when alone, and this did not differ based on whether cues were safety or threat cues.

In Study 2, I analyzed data collected from 71 individuals who were a subsample of a larger longitudinal study. Individuals in this sample underwent the same threat of shock task while fMRI data was collected, but their supportive partner was either a non-romantic friend, a non-cohabiting romantic partner, or a cohabiting romantic partner. I calculated LIs from the amygdala and the ECN, areas of the brain where hemispheric imbalance is associated with the EEG signal I utilized in Study 1. I used depression an anxiety measures obtained yearly by these participants to get three measures of psychopathology: 1) a measure of whether or not the participant had ever experienced a major depressive or major anxious episode, 2) their average depression and anxiety symptoms in the 7 years prior to the threat of shock task, and 3) their average depression and anxiety symptoms in the 8 years after the threat of shock task. I also used measures of perceived social support gathered both shortly before the participants engaged in the threat of shock task, and in the 8 years following the threat of shock task and measures of overall health, obesity, inflammatory markers, drinking behavior, and hard drug use obtained after the threat of shock task to see if changes in neural signals of approach and avoidance motivation moderated and/or mediated relationships between perceived social support and health outcomes.

Participants in Study 2 showed a more avoidance motivated neural response to threat cues than safety cues in both the ECN and amygdala. There was also a general effect of supportive touch, and participants in general showed a more approach motivated neural pattern when being supported than when alone. This was also true of both the ECN and the amygdala. Participants with a history of major anxious episodes showed a more approach motivated neural pattern when presented with threatening stimuli, and participants with a history of major depressive episodes showed a more avoidance motivated neural pattern. However, these effects were only seen in the amygdala. There was some indication that a history of major depressive episodes blunted the effect of a supportive partner in the amygdala, but only for participants whose partner was a romantic partner with whom they cohabitated. None of the moderation or mediation models in Study 2 showed a significant role for changes in approach and avoidance motivation, thought this was difficult to truly assess because perceived social support and physical health were not strongly linked in this sample.

Below, I translate these results into three main findings offered by this dissertation, followed by a discussion of the limitations of these studies and future directions.

Finding 1: Social support augments brain signals associated with approach and avoidance motivation, but not consistently across different neural measurement types.

In Study 1, I did not find the expected pattern of FAA I predicted. FAA obtained from participants in Study was not affected by cue type or condition. This may have been due to the limited scope of how I calculated FAA. I only obtained FAA from the F3/F4 lead pair, in order to align this study with the most common method of calculating FAA and protect against spurious findings through over-testing. However, other studies have found FAA effects from other frontal lead pairs, such as F5/F6 and F7/F8 (E. E. Smith et al., 2017).

In Study 2 cue differences elicited greater right-hemisphere dominance in both the ECN and amygdala, and supportive touch attenuated this effect in both ROIs. All models of the hand holding task demonstrated these two effects, validating the hypothesis that social support generally shifts an individuals motivational framework towards approach when facing threats that would otherwise elicit an avoidant reaction. Study 2 provides evidence that the aid of trusted individuals changes our orientation to potential threats in a way that prior literature has linked with beneficial outcomes.

Finding 2: Trait psychopathology is linked to differential approach and avoidance motivation when confronted with a threat, but maybe only in certain regions of the brain

While Study 1 did find a link between supportive condition, anxious apprehension symptoms, and depression symptoms, this finding was limited in many ways. First, if was only observed in F3 alpha power, and not in FAA. Because FAA is a robust marker of approach and avoidance motivation, and F3 was only analyzed to try and make sense of FAA effects, I will refrain from drawing strong conclusions linked to this finding.

Study 2 did find the expected main effects of a history of major anxious and major depressive episodes when utilizing the LI obtained from the amygdala, but these effects were not significant in ECN. This is in spite of previous literature linking asymmetry in the ECN to trait depression (Herrington et al., 2010; E. E. Smith et al., 2017; Zotev et al., 2016). Given the ECN's role in directed attention and other higher-order cognitive functions such as decision making (Hecht, 2010), we may not have elicited these difference due to the nature of the hand holding task. As the task is designed, there is no decision making or attentional allocation required on the part of participants. Participants are tasked with nothing except regulating their reaction to the startle of the shock cue, a role generally associated with the amygdala (Ressler, 2011).

Also, trait psychopathology was only observed to affect the LI obtained from the amygdala when it was indexed categorically, not when it was assessed using an average of historic symptoms. While this seems inconsistent on face value, this same pattern was observed by Smith and colleagues when examining FAA obtained during a resting-state task (E. E. Smith et al., 2017). Other biomarkers of psychopathology have been linked to diagnostic status, but not symptom severity. For example, meta-analytic data has shown that error-related negativity is a robust marker of OCD pathology status, but is not strongly linked to symptom severity (Riesel, 2019; Riesel et al., 2013). Difference in hemispheric dominance in anxiety and depression may represent a similar biomarker.

Finding 3: Trait psychopathology may blunt the effect of social support on approach and avoidance motivation, but only in specific contexts

Study 2 found evidence that a history of major depressive episodes was associated with a blunted reaction to support touch when facing a threat. However, this was only true of participants who were supported by a person who was a romantic partner with whom they cohabitated. Otherwise, no effect was seen of trait depression or anxiety on neural shifts in approach and avoidance motivation as a result of social support. Given that only 27 of the participants in Study 2 fit into this category, it may be that this was a spurious effect from comparing small samples. However, the estimated effect size of this interaction effect is quite large (std. β = -2.21) and thus warrants serious consideration. Perhaps individuals with a trait disposition towards depression exhibit a reduction in the benefits of social support if they are in consistent contact with a supporting individual.

Limitations

The findings of these studies need to be interpreted in light of several limitations. The first is that the participants selected for the studies in this dissertation were not assessed for psychopathology history beforehand, as neither sample was collected with the intention to test theories about depression and anxiety. One effect of this sampling is that the rate of depression in the sample roughly matches the overall population. While this is not a weakness in the context of generalizing the results either study was intended to probe, nonetheless it lowers the power in the statistical models used due to the large difference in cell sizes for categorical comparisons and the relative lack of variance for continuous effects. Interestingly, both samples featured a highly anxious distribution, with individuals exhibiting clinical levels of anxious apprehension over represented in both samples. This may be due to the fact that major anxious episodes were evaluated using previously obtained measures of trait anxiety, while major depressive episodes were obtained from the BDI-II, which asked about depressive symptoms over a two week span. Individuals may have experienced several major depressive episodes, all of which occurred between their yearly assessments. A more accurate way to assess major depressive episode history would have been a structure clinical interview, such as the one utilized by Smith and colleagues when assessing the differential effect of state and trait depression on FAA. However, since these analyses were conducted on datasets that were already gathered, this was not an option. As such, the findings of this study should be understood as an initial attempt to understand the role of psychopathology as a moderator or approach and avoidance motivation, rather than as a definitive test of the effects.

A second limitation is that the sample in Study 2 could not be used to examine moderation and mediation effects, because the expected relationship between perceived social support and physical health outcomes was not observed. This could be due to several possible limitations. First, the sample for the study was not selected via a stratified differentiation of perceived social support. It may be the case that these well-supported effects require a greater variance in perceived social support than was present in Study 2. Also, given the limited sample size for running complex SEM models, measures of physical health and social support were obtained using averages, rather than more robust and sophisticated methods such as latent factor scores or latent growth curve models. These more powerful ways of aggregating longitudinal data and partialing out relevant variance from error might have yielded models with the power to detect the relationship of interest. However, such models would require more than the 71 participants included in Study 2.

A third limitation is the data reduction workflow for the EEG data used in Study 1. While this workflow is well established and has been used in many previous studies, it relies on human judgement and therefore leaves room for error that might have been eliminated with a more automated processes such as the RELAX pipeline (Bailey et al., 2022). Aside from reducing the potential for human error in rejecting epochs and ICA components, such a pipeline might have made the results of this dissertation more reproducible. However, at the time that data was being processed for the dissertation, the RELAX pipeline and its validation studies had not been published.

Future directions

The studies in this dissertation provide a useful launching point for further probing the hypotheses presented from SAAT. These findings should be examined with a sample that is stratified by constructs on interest, such as perceived social support, psychopathology status, and physical health status. Also, different tasks which require different cognitive components of approach and avoidance should be tested. For example, the effect of social support on behavior and neural signals during tasks that require the resolution of approach/avoidance conflicts would offer insight into whether the effects and localization observed in this dissertation apply when a participant needs to choose some kind of action. It may be the case that these tasks elicit the expected responses in the ECN where a passive avoidance task did not.

Finally, an interesting line of research might be to see if dyadic support during neural stimulation to regions associated with approach and avoidance motivation enhances the effect of that stimulation. The dlPFC is frequently targeted for brain stimulation used to treat depression (Zhang et al., 2021). The integration of supportive partners into psychotherapy for individual disorders has yielded promising enhancements in effect size to treatment that are already the gold standard for depression, anxiety disorders, posttraumatic stress disorder, obsessive-compulsive disorder, eating disorders, and substance use disorders (Abramowitz et al., 2013; Baucom et al., 2014; Fischer & Baucom, 2018). Continuing to better understand the mechanisms by which social support exhibits benefits to individuals, specifically neural mechanisms, may be the key to understanding how we can extend these findings and potentially enhance the effects of biological interventions for psychopathology as well.

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Tables

Table 1: Full model for F3 Alpha power. Steps from left to right are main effects, two-way interactions, three-way interactions, and full four-way interaction. Condition *β*s indicate the slope of change from alone to partner condition. Cue *β*s indicate the slope of change from safety cue to threat.

	F3 Alpha Power																						
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*std. p*	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*std. p*	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*std. p*
Intercept	1.04	-0.06	-0.13 – 2.22	-0.28 – 0.16	0.081	2.00	-0.09	-0.01 – 4.00	-0.32 – 0.14	0.051	0.426	1.47	-0.09	-0.66 – 3.59	-0.32 – 0.14	0.175	0.445	1.52	-0.09	-0.64 – 3.69	-0.32 – 0.14	0.167	0.443
Condition	-0.03	-0.06	-0.08 – 0.02	-0.18 – 0.06	0.297	-0.30	-0.01	-0.97 – 0.37	-0.18 – 0.15	0.383	0.885	1.25	-0.02	-0.04 – 2.53	-0.19 – 0.14	0.057	0.770	1.13	-0.02	-0.43 – 2.69	-0.19 – 0.14	0.155	0.780
Cue	0.08	0.20	0.03 – 0.13	0.08 – 0.31	**0.001**	0.35	0.25	-0.32 – 1.03	0.08 – 0.41	0.305	**0.004**	0.05	0.25	-1.24 – 1.33	0.09 – 0.41	0.945	**0.003**	-0.07	0.25	-1.63 – 1.49	0.09 – 0.42	0.929	**0.003**
STAI-T	-0.02	-0.13	-0.04 – 0.01	-0.34 – 0.08	0.215	-0.04	-0.15	-0.08 – 0.01	-0.38 – 0.07	0.098	0.182	-0.02	-0.13	-0.07 – 0.02	-0.36 – 0.11	0.286	0.288	-0.03	-0.13	-0.07 – 0.02	-0.36 – 0.11	0.273	0.284
BDI-II	0.01	0.13	-0.01 – 0.03	-0.07 – 0.34	0.202	-0.14	0.09	-0.39 – 0.11	-0.14 – 0.31	0.267	0.454	-0.07	0.07	-0.34 – 0.20	-0.16 – 0.31	0.596	0.529	-0.08	0.07	-0.36 – 0.20	-0.16 – 0.30	0.563	0.536
Condition x Cue						-0.04	-0.10	-0.14 – 0.06	-0.34 – 0.13	0.402	0.402	-0.40	-0.10	-1.72 – 0.92	-0.33 – 0.13	0.550	0.393	-0.17	-0.10	-2.38 – 2.04	-0.34 – 0.13	0.880	0.386
Condition x STAI-T						0.01	0.05	-0.01 – 0.02	-0.07 – 0.17	0.427	0.427	-0.03	-0.02	-0.05 – -0.00	-0.18 – 0.15	**0.049**	0.839	-0.02	-0.01	-0.06 – 0.01	-0.18 – 0.15	0.140	0.864
Cue x STAI-T						-0.01	-0.04	-0.02 – 0.01	-0.16 – 0.07	0.464	0.464	0.00	-0.07	-0.03 – 0.03	-0.23 – 0.10	0.959	0.416	0.00	-0.07	-0.03 – 0.04	-0.23 – 0.10	0.851	0.437
Condition x BDI-II						0.00	0.05	-0.01 – 0.01	-0.07 – 0.17	0.420	0.420	-0.21	0.06	-0.35 – -0.07	-0.11 – 0.23	**0.004**	0.475	-0.19	0.06	-0.39 – 0.01	-0.10 – 0.23	0.060	0.461
Cue x BDI-II						0.00	0.01	-0.01 – 0.01	-0.11 – 0.13	0.895	0.895	0.08	0.06	-0.06 – 0.22	-0.11 – 0.23	0.255	0.478	0.10	0.06	-0.10 – 0.30	-0.10 – 0.23	0.323	0.464
STAI-T x BDI-II						0.00	0.13	-0.00 – 0.01	-0.08 – 0.34	0.236	0.236	0.00	0.07	-0.00 – 0.01	-0.16 – 0.30	0.558	0.558	0.00	0.08	-0.00 – 0.01	-0.16 – 0.31	0.527	0.527
Condition x Cue x STAI-T												0.01	0.07	-0.02 – 0.04	-0.16 – 0.30	0.554	0.554	0.00	0.06	-0.04 – 0.05	-0.17 – 0.30	0.881	0.588
Condition x Cue x BDI-II												-0.01	-0.08	-0.03 – 0.01	-0.31 – 0.15	0.485	0.485	-0.04	-0.09	-0.33 – 0.24	-0.32 – 0.15	0.758	0.466
Condition x STAI-T x BDI-II												0.00	0.19	0.00 – 0.01	0.07 – 0.31	**0.002**	**0.002**	0.00	0.17	0.00 – 0.01	0.00 – 0.34	**0.050**	**0.050**
Cue x STAI-T x BDI-II												-0.00	-0.07	-0.00 – 0.00	-0.19 – 0.05	0.278	0.278	-0.00	-0.08	-0.01 – 0.00	-0.25 – 0.09	0.343	0.343
Condition x Cue x STAI-T x BDI-II																		0.00	0.03	-0.01 – 0.01	-0.21 – 0.27	0.796	0.796
Random Effects																							
σ^2	0.05					0.05						0.05						0.05					
τ_{00}	0.13 $_{ID}$					0.13 $_{ID}$						0.13 $_{ID}$						0.13 $_{ID}$					
ICC	0.74					0.73						0.74						0.74					
N	74 $_{ID}$					74 $_{ID}$						74 $_{ID}$						74 $_{ID}$					
Observations	294					294						294						294					
Marginal R^2 / Conditional R^2	0.042 / 0.750					0.058 / 0.750						0.067 / 0.759						0.067 / 0.759					

	Amygdala LI				
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*
Intercept	-0.24	-0.08	-0.34 – -0.13	-0.33 – 0.18	**<0.001**
Condition	0.15	0.45	0.05 – 0.25	0.16 – 0.74	**0.003**
Major Anxious Episodes	0.16	0.23	0.03 – 0.30	0.04 – 0.43	**0.019**
Major Depressive Episodes	-0.17	-0.50	-0.31 – -0.03	-0.93 – -0.08	**0.021**
Random Effects					
σ^2	0.08				
$\tau_{00\ ID}$	0.02				
ICC	0.15				
N_{ID}	71				
Observations	142				
Marginal R^2 / Conditional R^2	0.105 / 0.243				

Table 2: Model summary for main effects of hierarchical linear models predicting LI obtained from the Amygdala.

Figures

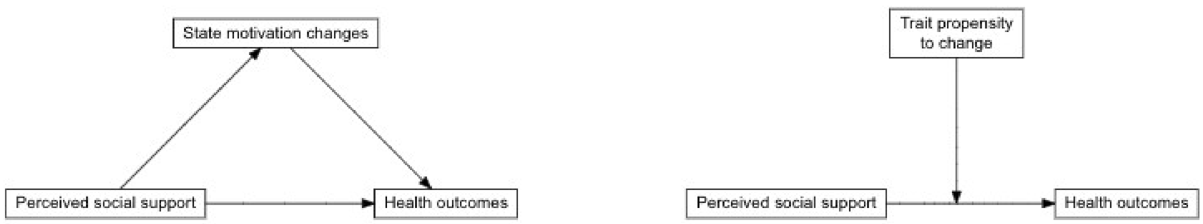

Figure 1: Basic overview of theoretical model for changes in approach and avoidance motivation as both a mediator and moderator of the relationship between perceived social support and health outcomes.

Figure 2: Basic overview of models testing mediation (right) and moderation (left) effects of changes in approach and avoidance motivation on the relationship between perceived social support and physical health

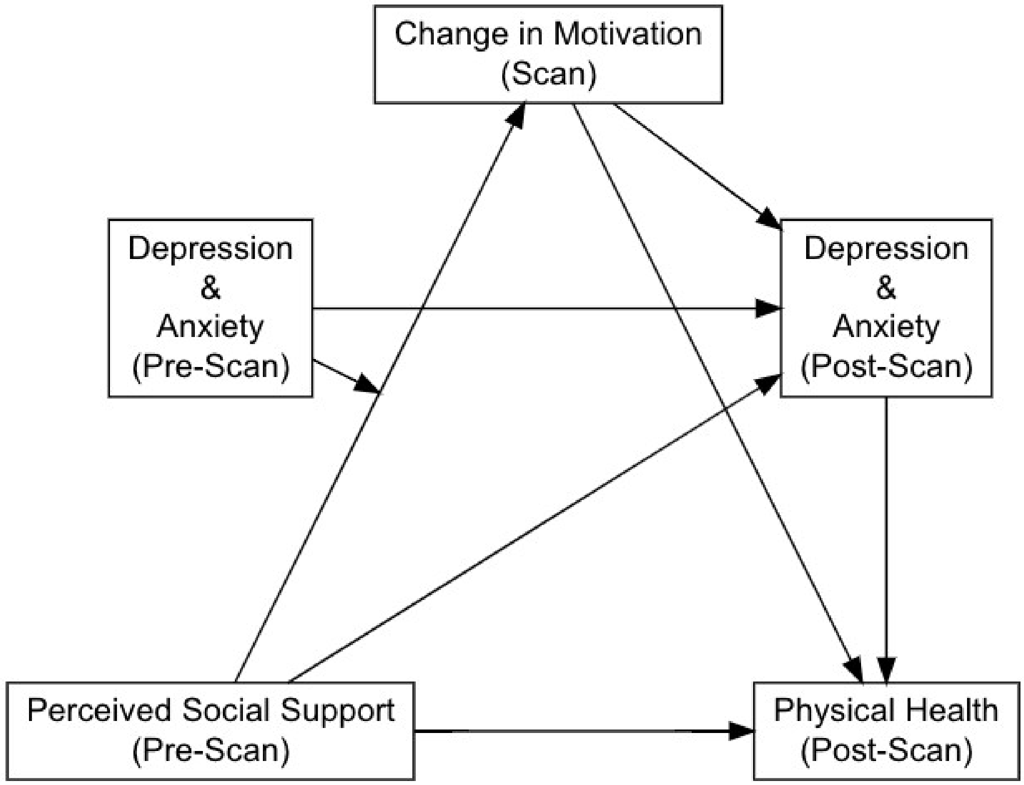

Figure 3: Basic overview of model testing the mediation of the relationship between perceived social support (independent variable) and internalizing symptoms and physical health (dependent variables)

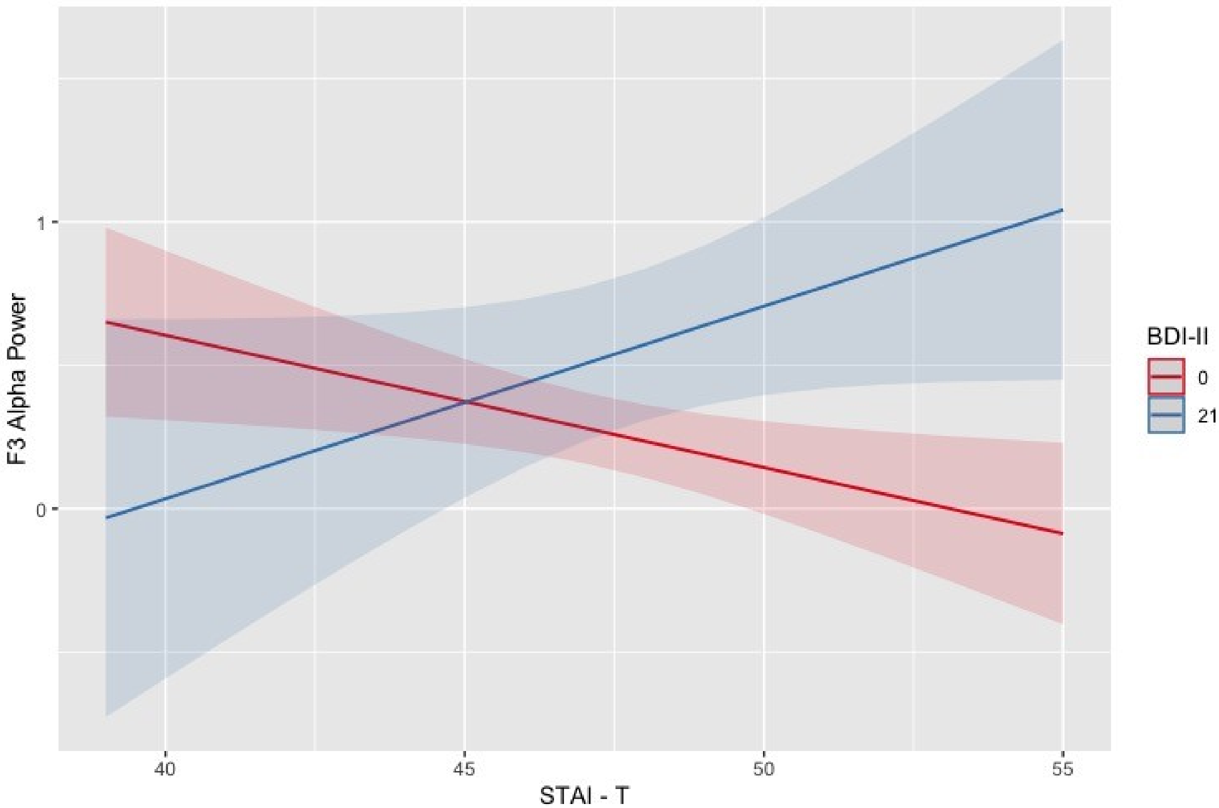

Figure 4: Plot of STAI-T and BDI-II interaction effect from hierarchical linear model of alpha power at F3 during partner condition.

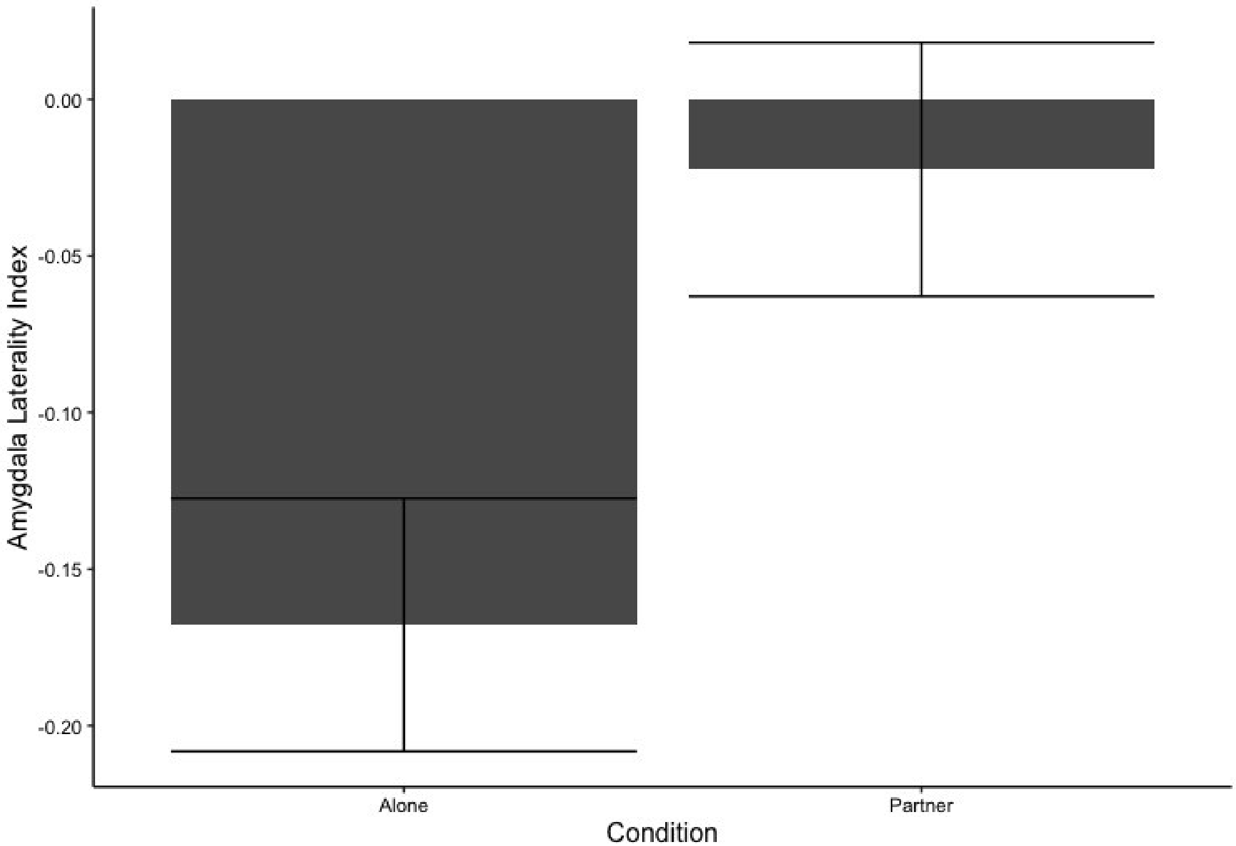

Figure 5: Plot of the main effect of condition on the laterality index calculated from the amygdala.

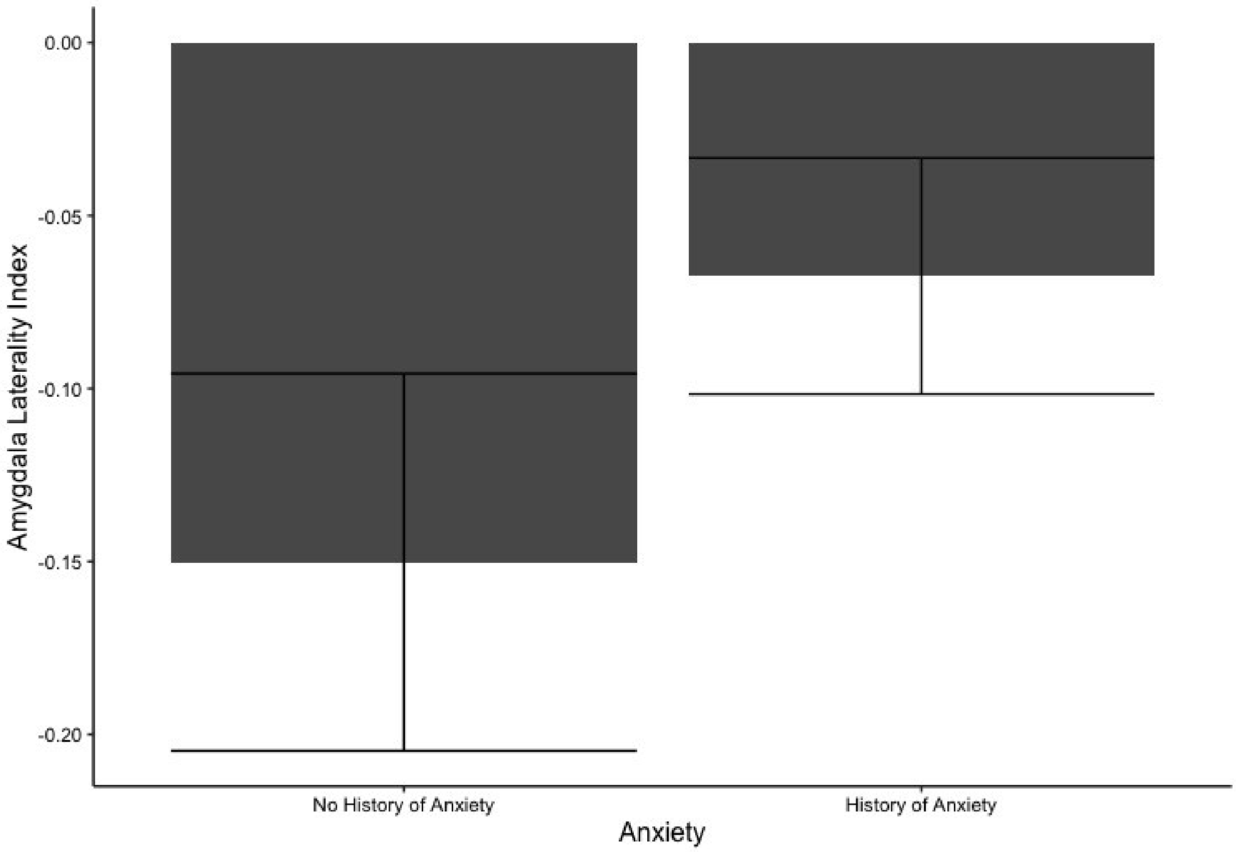

Figure 6: Plot of the main effect of a history of major anxious episodes on the laterality index calculated from the amygdala.

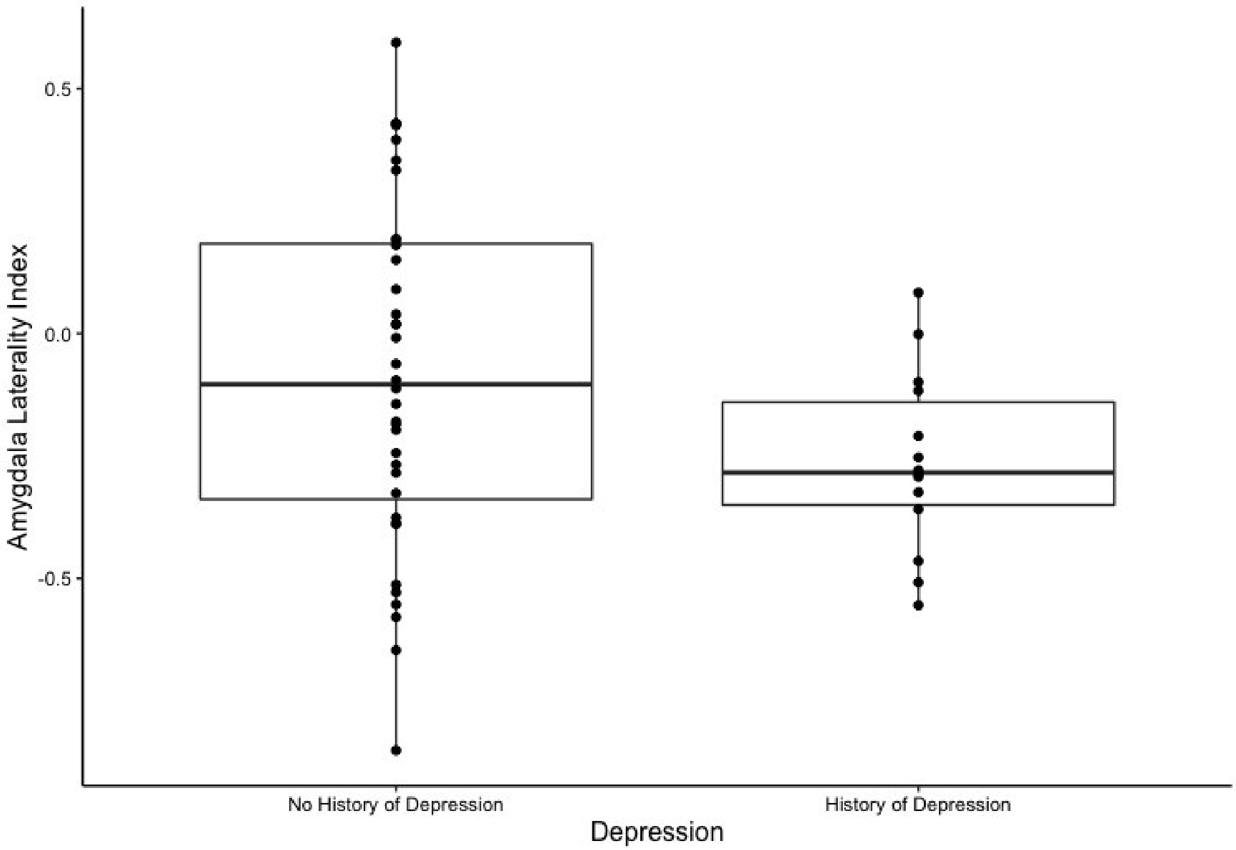

Figure 7: Plot of the main effect of a history of major depressive episodes on the laterality index calculated from the amygdala among individuals whose supportive partner was a non-cohabiting romantic partner.

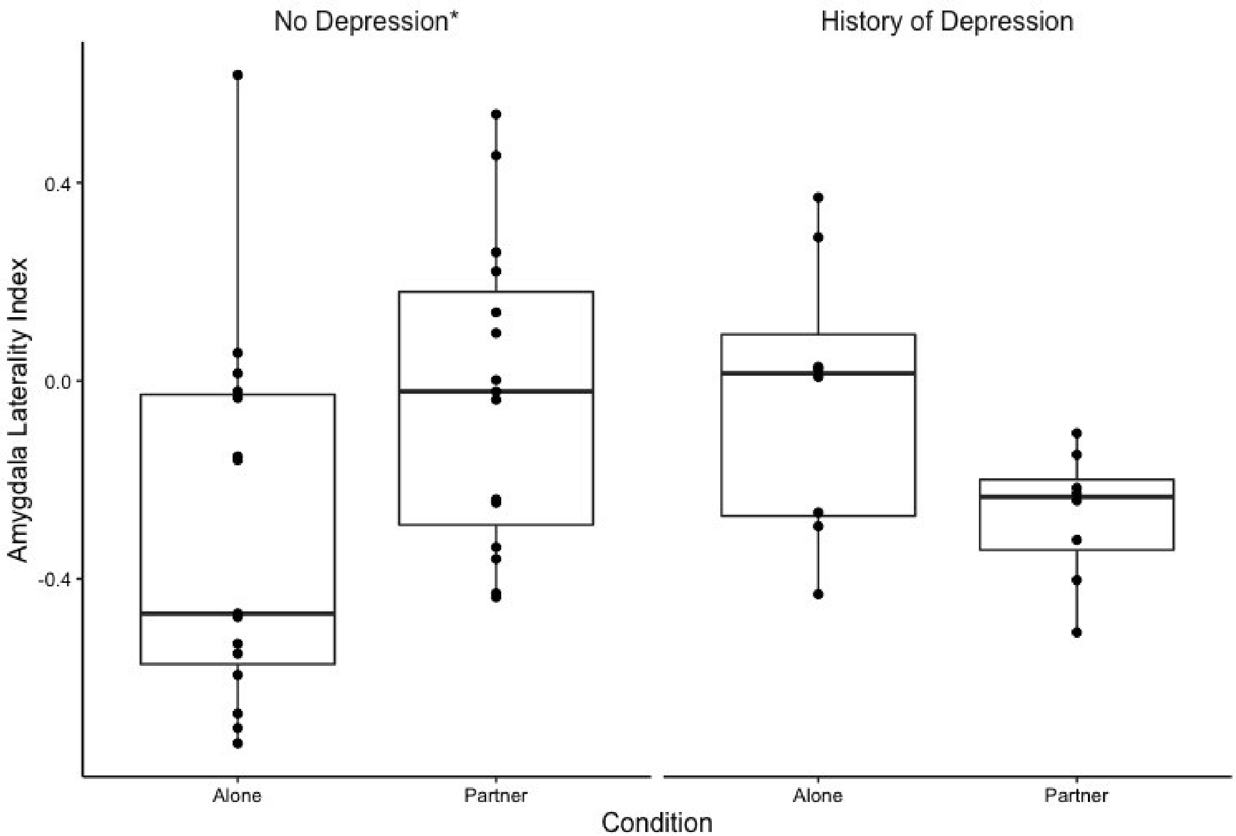

Figure 8: The two-way interaction between condition and history of major depressive episodes among individuals whose supportive partner was a cohabiting romantic partner. The condition effect was not significant for individuals with a history of a major depressive episode.