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Prefrontal recruitment during social rejection predicts greater subsequent self-regulatory imbalance and impairment: neural and longitudinal evidence ☆

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ABSTRACT

Social rejection impairs self-regulation, yet the neural mechanisms underlying this relationship remain unknown. The right ventrolateral prefrontal cortex (rVLPFC) facilitates self-regulation and plays a robust role in regulating the distress of social rejection. However, recruiting this region's inhibitory function during social rejection may come at a self-regulatory cost. As supported by prominent theories of self-regulation, we hypothesized that greater rVLPFC recruitment during rejection would predict a subsequent self-regulatory imbalance that favored reflexive impulses (i.e., cravings), which would then impair self-regulation. Supporting our hypotheses, rVLPFC activation during social rejection was associated with greater subsequent nucleus accumbens (NAcc) activation and lesser functional connectivity between the NAcc and rVLPFC to appetitive cues. Over seven days, the effect of daily felt rejection on daily self-regulatory impairment was exacerbated among participants who showed a stronger rVLPFC response to social rejection. This interactive effect was mirrored in the effect of daily felt rejection on heightened daily alcohol cravings. Our findings suggest that social rejection likely impairs self-regulation by recruiting the rVLPFC, which then tips the regulatory balance towards reward-based impulses.

Social rejection is not merely an inconvenience, it has been a long-standing and profound threat to health and reproduction throughout human history and into modernity (Baumeister and Leary, 1995; Cacioppo and Patrick, 2008; Williams, 2007). Social rejection threatens human needs to belong, maintain a favorable self-view, exert control over the environment, and feel that one's existence is meaningful (Williams, 1997, 2009). In addition to these threats, social rejection reduces individuals' efforts towards self-regulation and subsequently leads to self-regulation failures (Baumeister et al., 2005; DeWall et al., 2008; Oaten et al., 2008). For instance, compared to their non-rejected counterparts, rejected participants persisted less when faced with failure and ate more unhealthy food (Baumeister et al., 2005). Rejection's deleterious effect on self-regulation is particularly important to understand because the ability to successfully engage in self-regulation is a uniquely powerful predictor of life outcomes such as criminality, academic performance, and interpersonal relationship health (Gottfredson and Hirschi, 1990; Tangney et al., 2004). Indeed, many societal problems (e.g., substance abuse, violence) can be readily construed as stemming directly from self-regulatory failure (Baumeister and Vohs, 2003).

To date, the neuroscientific literature is relatively silent in explaining the link between social rejection and impaired self-regulation. We propose to fill this gap by combining fMRI and longitudinal methodologies to assess the potential role that recruitment of the lateral prefrontal cortex during social rejection may play in the effect of rejection on self-regulatory failure.

Theories of self-regulation failure: strength, motivation, and balance

Completing a task that that requires greater self-regulatory effort often leads to subsequent self-regulatory impairment (e.g., Baumeister et al., 1998). One of the leading explanations for this phenomenon is the strength model of self-regulation, which posits that self-regulation relies upon a reservoir of regulatory ability that can be fatigued much like a muscle (Baumeister and Heatherton, 1996). According to the strength model, self-regulatory impairment occurs when this top-down, inhibitory, regulatory resource is fatigued by other demanding tasks. This model has received substantial empirical support (Hagger et al., 2010; Hofmann et al., 2012a,b).

Neuroscientific research has identified the neuroanatomical seat of this regulatory resource in the lateral prefrontal cortex (lateral PFC; Cohen and Lieberman, 2010; Cohen et al., 2012; Heatherton and Wagner, 2011; Lieberman, 2011). Just as the strength model would

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predict, the more individuals tend to use the lateral PFC to regulate their impulses (e.g., racial bias), the less regulatory effort they then exert on subsequent tasks (Richeson et al., 2003). As would be predicted by the strength model, the lateral PFC likely becomes 'fatigued' due to greater initial use, predicting greater subsequent self-regulatory impairment. Crucially, this is not to say that the lateral PFC is *unable* to exert self-regulatory influence; it is just less likely to do so, much like a muscle that can function after intense exercise, yet would require more motivation for to do so (e.g., an oncoming car). Indeed, the seminal research on the link between social rejection and self-regulatory impairment found that the link could be broken when participants were given adequate incentives for their performance (Baumeister et al., 2005).

An alternative account of self-regulatory failure has arisen which de-emphasizes the notion that self-regulation is a resource that can become fatigued and instead posits that self-regulatory exertion shifts motivation, attention, and emotion away from superordinate goals (e.g., weight loss) and towards impulses (e.g., food cravings; Inzlicht and Schmeichel, 2012; Inzlicht et al., 2014). Much like the strength model, this motivational model of self-regulation would predict that greater lateral PFC use during a self-regulatory task, an index of self-regulatory effort, would lead to lesser subsequent activation of this region as motivation and attention shifted to more impulsive, subcortical neural substrates (e.g., the nucleus accumbens).

Findings from cognitive neuroscience have been used to incorporate and expand upon models of self-regulation, taking the form of balance theory (Heatherton and Wagner, 2011). The balance perspective integrates literature on the role of the lateral PFC in facilitating self-regulation by inhibiting subcortical activity that often undermines self-regulation, stemming from regions such as the amygdala and nucleus accumbens. According to balance theory, self-regulation involves a tenuous balance between the activity of bottom-up, subcortical neural regions and top-down, prefrontal neural regions. Self-regulatory failure occurs when the balance is tipped in favor of the subcortical regions. Supporting this notion, individuals who experience self-regulatory fatigue show greater bottom-up reward activation to appetitive targets and reduced connectivity between the nucleus accumbens and lateral prefrontal regions (Wagner et al., 2013). Integrating these theories and findings, social rejection is thus likely to impair self-regulation by recruiting the neural seat of self-regulation, the lateral PFC, which may subsequently tip the brain's self-regulatory balance towards the activity of subcortical regions and the impulses they elicit. These impulses may then overpower top-down, inhibitory processes and relate to later self-regulatory impairment. Thus, enhanced activation in the lateral PFC to social rejection may place people at risk for self-regulation impairments, specifically those that stem from bottom-up cravings such as alcohol consumption.

The rVLPFC: involvement in the regulation of social rejection

Seminal neuroscientific research on social rejection has shown that the right ventrolateral PFC (rVLPFC) occupies the inferior frontal gyrus and plays a robust regulatory role during instances of exclusion (Eisenberger et al., 2003). Across several studies, rVLPFC activation during rejection predicted less self-reported distress and activation in neural regions that subserve painful distress, suggesting a regulatory function (Eisenberger et al., 2003, 2007; Onoda et al., 2009). Confirming this regulatory role, electrical stimulation of the rVLPFC during social rejection attenuated participants' reports of distress and aggressive responses (Riva et al., 2012, in press). These findings fit well with other neuroimaging research that identify the rVLPFC as a neural region that generally subserves inhibition and top-down control of the amygdala and nucleus accumbens in the service of effective self-regulation (Berkman and Lieberman, 2009; Berkman et al., 2014; Cohen et al., 2012; Lieberman, 2011; Ochsner and Gross, 2005; Wager et al., 2008; Wagner et al., 2013).

These findings support the prediction that social rejection may impair self-regulation by recruiting the rVLPFC to manage the aversive experience of social rejection. This recruitment would then, if partially, reduce the amount of self-regulatory exertion on a subsequent self-regulatory task, as shown in previous research on the lateral PFC (e.g., Richeson et al., 2003). As predicted by balance theory, this self-regulatory impairment would tip the neural balance in favor of subcortical neural regions that generate affective and reward-based impulses (Heatherton and Wagner, 2011). Neuroimaging research has implicated the nucleus accumbens (NAcc) as a crucial substrate of cravings and reward-based impulses in response to appetitive cues and possesses strong regulatory ties to the VLPFC (e.g., food; Wagner et al., 2013).

Reflecting an impaired regulatory tendency, we predicted that greater rVLPFC activation during social rejection would be associated with greater subsequent activation of the nucleus accumbens to appetitive cues. Providing evidence of a regulatory imbalance, we further predicted that rejection-specific rVLPFC activation would predict reduced functional connectivity between the rVLPFC and NAcc. Functional connectivity estimates the degree to which neural regions' activity synchronizes or desynchronizes over the time and across situations with greater coupling suggesting an interaction between two regions and lesser coupling suggesting the two regions function more orthogonally (Rogers et al., 2007).

Reflecting a growing trend in using neural signatures to predict outcomes in everyday life (i.e., the brain-as-predictor approach; Berkman and Falk, 2013; Berkman et al., 2011; Falk et al., 2012), we sought to test these predictions combining functional magnetic resonance imaging (fMRI) with a daily diary approach. We hypothesized that daily reports of perceived social rejection would be associated with self-regulatory impairment among individuals who expressed a relatively higher level of rVLPFC activation during social rejection. Based on our balance theory perspective, we also hypothesized that daily reports of perceived social rejection would be associated with greater cravings for appetitive items (i.e., alcohol) among individuals who expressed a relatively higher level of rVLPFC activation during social rejection. Alcohol use was selected because it is a particularly acute self-regulation issue for undergraduates and has substantial consequences for life outcomes (Crawford and Novak, 2006).

To do so, participants completed 7 days of daily diaries and then entered our fMRI scanner where they were socially accepted and then rejected and then passively viewed appetitive, drug, and neutral stimuli while undergoing fMRI. The fMRI scan was performed last because we did not want the experimental induction of social rejection to contaminate subsequent daily reports of rejection. We conceptualized the fMRI scan as a measure akin to a personality questionnaire in which rank-order differences in neural activation obtained from this scan were assumed to be durable across time. This assumption is based on a considerable amount of evidence showing that neural responses obtained with fMRI correspond to such durable characteristics as Big Five personality trait clusters (DeYoung, 2010) and long-term behavioral outcomes such as smoking cessation (Berkman et al., 2011).

Materials and methods

Participants

Forty undergraduates who reported being neurologically and psychologically healthy participated in the study for course credit and money. Due to the confined and magnetic nature of the MRI environment, we excluded obese, claustrophobic, color blind, and pregnant individuals from participating as well as individuals who reported metal inside of their bodies, the use of psychoactive medication, or a history of seizures.

One participant distorted their fMRI data during the Cyberball task by repeatedly itching their face with the response glove. Two more participants failed to pass quality assurance items on their daily diaries in which they were asked to select a given number to ensure their