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The Salience Network structures as a mediator of violence and perceptions of hostility

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ABSTRACT

This study investigates the surface area of salience network structures as a mediator of violence and perceptions of hostility in a sample of 1112 healthy adult brains. Correlational Analyses revealed that all variables were correlated except the bilateral anterior cingulate and perceptions of aggression. Structural Equation Modeling was used to conduct this analysis including one latent variable, the salience network, which is comprised of surface area of the bilateral anterior cingulate and the bilateral insular cortex. Results indicate the model displayed significant fit and salience network area mediated self-reported perceptions of hostility and aggression. The implication of these findings are discussed in the context of current findings and future research.

Keywords: Salience Network; perceived hostility; aggression; structural equation modeling; insular cortex; anterior cingulate

1. Introduction

Aggressive acts have plagued the human condition throughout recorded history (Anderson & Huesman, 2003). Violence, a physical form of aggression, is a concern for modern society since exposure to acts of violence can increase hostile attributions and lead to neurological changes, increasing the propensity to engage in more violent or aggressive acts (Bushman & Anderson, 2002; De Bellis, 2005). Understanding the intersection of perceptions of hostility, the brain, and aggression may be useful in developing an intervention for violence and other forms of aggression.

While several studies have focused on isolated brain regions, research in neuroscience suggests that brain function can be linked to large scale brain networks (Bressler & Menon, 2010; Sporns, 2013). One important brain network that has been identified is the salience network (SN; Fox et al., 2005; Raichle et al., 2001). Research suggests that the SN is involved in a variety of functions including attention, motivation, social processing, decision making, and threat perception (Dosenbach et al., 2006; Everaert, Tierens, Uzieblo, & Koster, 2013; McCrory et al., 2011; Pichon, de Gelder, & Grèzes, 2012; Sadaghiani et al., 2010; Seeley et al., 2007; Singer, Critchley, & Preuschoff, 2009; Uddin, 2016). Research has also linked irregularities in the SN to violence and aggression (Aharoni et al., 2013; Ettinger, Corr, Mofidi, Williams, & Kumari, 2013; Krishnadas, Palaniyappan, Lang, McLean, & Cavanagh, 2014; Philippi et al., 2015; Trzepacz et al., 2013). Moreover, heightened perceptions of hostility are often characteristic of violence and aggression (Bartholow, Sestir, & Davis, 2005; Bonus, Peebles, & Riddle, 2015; Bushman, 2016; Bushman & Anderson, 2002; Hasan, Bègue, & Bushman, 2012; Mellentin, Dervisevic, Stenager, Pilegaard, & Kirk, 2015), also associated with the SN (McCrory et al., 2011; Pichon et al., 2012). The next two sections of this manuscript discuss the intersection of hostile perceptions, the SN, and aggression.

Salience Network and Aggression

Attention is the act of selectively processing aspects of one's environment, allowing individuals to focus on information for further processing. How attention is directed depends on the physical and motivational characteristics of afferent stimuli that make them salient (Connor, Egeth, & Yantis, 2004; Öhman, Flykt, & Esteves, 2001; Humphrey, Underwood, & Lambert, 2012; Rowe, Hirsh, & Anderson, 2007; Tamir & Robinson, 2007), allowing the individual to prioritize attention and engage in further processing (Everaert et al., 2013). The detection of salience is thought to be subserved by a network of cortical and subcortical brain areas centered around the anterior insula and anterior cingulate, which play an important role in neural responses to novel and/or motivationally-relevant cues (Dosenbach et al., 2006; Sadaghiani et al., 2010; Seeley et al., 2007; Uddin, 2016). Insular activity, in particular, activity of the dorsal anterior insula is correlated with salience, especially that associated with homeostatic, emotional, or cognitive factors (Uddin, 2016).

The SN is recruited in attentionally-demanding tasks, in addition to areas associated with executive control such as frontal and parietal areas. Networks associated with salience and executive control are believed to have inhibitory, reciprocal connections with areas linked to the default mode network (DMN) such as the precuneus and lateral parietal cortex, posterior cingulate cortex, and medial prefrontal areas (Fox et al., 2005; Raichle et al., 2001). Neuroimaging studies suggest that the SN and associated brain regions (e.g., amygdala) are involved in threat detection (McCrory et al., 2011; Pichon et al., 2012) and the anticipation of pain (Wiech et al., 2010). Thus, the SN is likely to play a key role in integrating emotional, sensory and motor information to guide the processing of social and emotional information and subsequent decision-making and social processing (McCrory et al., 2011; Singer et al., 2009). Indeed, dysfunction in the SN has been associated with a number of clinical consequences ranging from neurodevelopmental to affective and neurodegenerative disorders (see Uddin, 2016 for a review).

SN dysfunction has been linked to violence, aggression, psychopathy, and criminal behavior (Aharoni et al., 2013; Ettinger et al., 2013; Krishnadas et al., 2014; Philippi et al., 2015; Trzepacz et al., 2013). Specifically, evidence suggests that SN abnormalities are linked with aggression (Tzepacz et al., 2013) and criminal recidivism (Ettinger et al., 2013; Philippi et al., 2015). Moreover, psychopathy has been connected with increased anatomical surface area in the SN (Krishnadas et al., 2014). In addition, SN dysfunction has been linked to impulsivity and impaired emotional and behavioral regulation in violent individuals (Ettinger et al., 2013; Philippi et al., 2015).

Perceptions of Hostility and Aggression

As mentioned previously, the SN plays a role in evaluating threat, prioritizing attention, and the processing of motivationally-relevant stimuli (Everaert et al., 2013; Dosenbach et al., 2006; Connor et al., 2004; McCrory et al., 2011; Öhman, et al., 2001; Pichon et al., 2012; Rowe et al., 2007; Sadaghiani et al., 2010; Seeley et al., 2007; Tamir & Robinson, 2007; Uddin, 2016). This suggests that the SN is associated with perceiving threat or appraising the motivations of others as hostile. Researchers have accepted that there are members of the population that have Hostile Perception which refers to the process of recognizing and interpreting cues as threatening even in ambiguous situations or attributing ambiguous behavior as hostile (Combs et al., 2009). Findings indicate a link between aggression and perceptions of hostility and suggests that perceiving the motivations of others as threatening can lead to an aggressive response (Bartholow et al., 2005; Bonus et al., 2015; Bushman, 2016; Bushman & Anderson, 2002; Hasan et al., 2012; Mellentin et al., 2015).

Studies have shown that exposure to violence (e.g., playing violent video games) increases hostile attributions (Bonus et al., 2015; Bushman, 2016; Hasan et al., 2012). Specifically, Bonus and colleagues (2015) found that the combination of frustration and exposure to violence leads to an increase in hostile attributions. Bushman (2016) conducted a meta-analysis which included over 37 studies and a sample size of 10,410 and found that exposure to violent media has a small to moderate correlation ($r = 0.2$) with hostile appraisal.

Previous studies have linked hostile appraisal to aggression. For example, Hasan et al., (2012), found that self-reported hostile intentions were a key predictor of acts of aggression, Krahé and Möller, (2004) discovered that hostile attributions predicted acceptance of violent norms and attraction to violent electronic games, and Bushman and Anderson (2002) observed that exposure to violence (a violent video game) increased hostile attributions and anger. Furthermore, Mellentin and colleagues (2015) conducted a meta-analysis comparing aggressive individuals (e.g., psychopathy, antisocial personality disorder, and conduct disorder) to a control group and ascertained that aggressive participants perceived ambiguous faces as more aggressive than controls. Hasan et al. (2013) showed that repeated exposure to violence leads to increases in self-reported hostile expectation and an increased propensity to aggress against a confederate. Yeager, Miu, Powers, and Dweck (2013) demonstrated that hostile perceptions mediated personality traits and aggressive desire and that interventions that led to a decrease in hostile intention also led to a decrease in aggressive desire over eight months.

In summary, results from these studies indicate that perceptions of hostility and the SN are connected with aggression. Given that the SN is involved in attention and aggression, as noted previously, it is reasonable to suspect that the SN also plays a key role in perceiving hostility. Furthermore, these studies show that perceptions of hostility lead to aggression and, since the SN is directly involved in perception, it is rational to expect that the SN mediates the relationship between perceptions of hostility and aggression.

STATA Data Analysis and Statistical Software, version 15 (STATA, 2017) Structural Equation Modeling (SEM) was used in the current study to investigate whether the structural area of two key regions of the SN (the insular cortex and anterior cingulate) mediates the relationship between perceptions of hostility and aggression. For a visual representation of this model please refer to Figure 1. Specifically, this study used SEM to investigate the fit of a model that assumes that self-reported threat of hostility leads to increased surface area in the SN which, in turn, leads to higher levels of self-reported aggression.

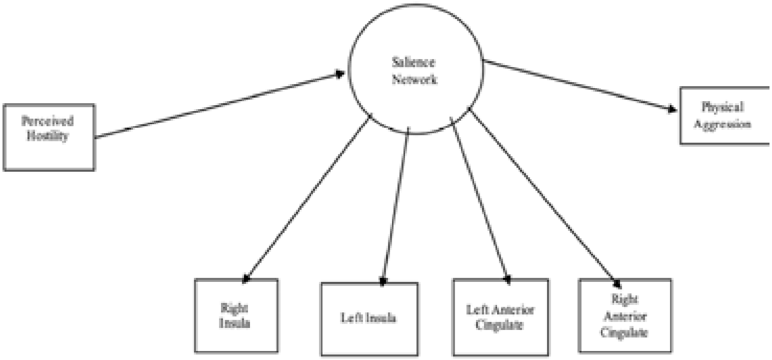

Figure 1. Salience Network as a mediator between Perception of Hostility and Aggression

2. METHOD

2.1 Participants

Data were collected as part of the Human Connectome Project (HCP), an open access big data initiative dedicated to understanding brain function and behavior (Van Essen et al., 2013). The sample was from the March 01, 2017 data release (Van Essen & Ugurbil, 2017). Behavioral and demographic data were analyzed from 1112 healthy adult monozygotic and twins dizygotic twins and their non-twin siblings (54.6% women) with ages ranging from 22 to 35 (Van Essen et al., 2013). Participants completed a comprehensive battery of assessment tools including the NIH Toolbox for Assessment of Neurological and Behavioral function (www.nihtoolbox.org) and auxiliary measures. The Toolbox includes measures of cognitive, emotional, motor and sensory processes in healthy individuals. Participants also completed measures of visual processing, personality and adaptive function, fluid intelligence, behavioral measures of emotion processing, and delay discounting. The HCP sample was selected for analysis as the inclusion of MZ and DZ twins and their non-twin siblings increases statistical power when analyzing heritability and distinguishing between genetic and environmental influences (Van Essen et al., 2013).

All subjects were scanned of the course of a three-year period at Washington University using a customized Siemens 3 Tesla "Connectome Skyra" scanner (See Van Essen et al., 2013 for details). Structural pre-processed data collected by the HCP (see Van Essen et al., 2013 for an overview of the preprocessing pipelines used) was assessed in 1112 individuals. Cortical surfaces of all HCP subjects were processed using FreeSurfer, followed by registration to the Conte69 surface-based atlas and the '164k_fs_LR' atlas mesh (Van Essen, Glasser, Dierker, Harwell, & Coalson, 2012).

2.2 Perceived Hostility

Perceived hostility was assessed by self-report as part of the NIH Toolbox on Emotion Battery, which includes various measures of structure, extent and quality of three aspects of social relationships (Gershon et al., 2013). One aspect of social relationships is social distress; the extent to which an individual perceives his/her daily social interactions as negative or distressing. The Perceived Hostility Survey questionnaire is an 8-item measure of social distress that measures aspects of perceived hostility. For example, "How often people argue with me, yell at me, or criticize me" (1= "Never" to 5= "Always"). Higher values suggest higher levels of perceived hostility.

2.3 Physical Aggression

Physical aggression was assessed by self-report as part of the NIH Toolbox on Emotion Battery, which includes various measures of three major components of negative affect (Gershon et al., 2013). One component of negative affect is Anger, which is characterized by attitudes of hostility and cynicism and often associated with experiences of frustration impeding goal-directed behavior. The Anger-Physical Aggression Survey questionnaire is a 5-item measure of aggression as a behavioral component. For example, "If I am provoked enough, I may hit another person" (1= "Extremely untrue of me" to 7= "Extremely true of me"). Higher values suggest higher levels of physical aggression.

3. Results

Correlational results are displayed in Table 1. The analyses revealed that the area of left insular cortex was significantly correlated with right insular cortex area ($r = .76$, $p < .05$), left anterior cingulate area ($r = .46$, $p < .05$), right anterior cingulate area ($r = .49$, $p < .05$), perceived hostility ($r = .10$, $p < .05$), and aggression (*r* = .10, $p < .05$). Similarly, the area of the right insular cortex was significantly correlated with left insular cortex area (*r*= .76, $p < .05$), left anterior cingulate area (*r* =.43, $p < .05$), right anterior cingulate area (*r* =.49, $p < .05$), perceived hostility (*r* = .11, $p < .05$), and aggression (*r* = .11, $p < .05$). Left anterior cingulate area was significantly correlated with right anterior cingulate area (*r* = .45, $p < .05$) and aggression (*r* = .12, $p < .05$) but not perceived hostility (*r* = .07, $p > .05$). The area of the right anterior cingulate was correlated with associated with aggression (*r* = .12, $p < .05$) and perceived hostility (*r* = .07, *p*<05).

SEM was conducted to test whether the area of the SN successfully mediated participants' perceptions of hostility and aggression. This model indicated adequate fit; χ^2= 167.93, $p < .05$, *RMSEA* = .126, $p < .05$, 95% *CI* = (.11, .14), *CFI* = .91, *TLI* = .85, *SRMR* = .064 (Hu & Bentler, 1999), which indicates that the model fits the observed covariance. In terms of the specific pathways, SN strength predicted the area in the right insular cortex (z = 30.26, $p < .05$), the left insula (z = 30.36, $p < .05$), the right anterior cingulate (z = 17.85, $p < .05$), the left anterior cingulate (z = 19.62, $p < .05$), and aggression (z = 3.77, $p < .05$). In addition, perceptions of hostility predicted the SN strength (z = 3.76, $p < .05$).

Table 1. Correlation table for perceptions of hostility, key regions in the Salience Network and Aggression

	Perceptions of Hostility	Right IC	Left IC	Right AC	Left AC	Aggression
Perceptions of Hostility	1					
Right IC	.11**	1				
Left IC	.10**	.76**	1			
Right AC	.03	.34**	.31**	1		
Left AC	.03	.35**	.35**	.25**	1	
Aggression	.31**	.11**	.10**	.08**	.10**	1

* p< .05 ** p< .01 IC= Insular Cortext, AC=Anterior Cingulate

4. Discussion

The SN, a diffuse network of brain areas centered around the anterior insula and anterior cingulate (Menon & Uddin, 2010; Seeley et al., 2007), is thought to play a central role in the ability to shift from an internally-oriented resting state mode to an externally-oriented task-processing mode (Menon & Uddin, 2010), and has been linked to aggression and other anti-social behaviors (Aharoni et al., 2013; Ettinger et al., 2013; Krishnadas et al., 2014; Philippi et al., 2015; Trzepacz et al., 2013). The current study examined relationships between the area of the insula and the anterior cingulate and hostility and aggression using SEM. The resultant model showed that structural data can lead to confirmatory models of brain networks and suggests that the SN mediates perception and emotional arousal. Specifically, these results show that the relationship between perceptions of hostility and aggression is at least partially due to the strength of the SN.

Given that the SN is interconnected with the DMN and executive control network (ECN), it is important to consider their involvement in SN function (Heatherton & Wagner, 2011). The ECN specifically has been tied to self-regulation which is vital for preventing aggressive acts before they occur (Boccardi et al., 2013). Similarly, the DMN has been interconnected with self-awareness and violence (Thijssen et al., 2015). Understanding how the different networks interact among violent people could lead to a better understanding of violence and related topics such as psychopathy. Along those lines, evidence suggests that the SN directs the ECN and DMN (Barrett & Satpute, 2013) which means that an intervention targeting the SN may lead to changes in the other two networks.

Considering that the SN directs other brain networks associated with violence and that the SN mediates perceptions of hostility and violence, then one should consider targeting the SN in an intervention rather than the perceptions themselves when trying to treat violent behavior. One intervention that shows promise in this area is mindfulness, which has been tied changes in the SN (Doll, Holzel, Boucard,Wohlschlager, & Sorg, 2015), and has been used successfully as an intervention to reduce violence (Shonin, Van Gordon, Slade, & Griffiths, 2013). A trait worthy of discussion is self-compassion. Self-compassion has been tied to key regions of the SN (Klimecki, Leiberg, Lamm, & Singer, 2013; Longe et al., 2010; Moadab, 2013). Self-compassion also shows promise as a potential antidote to violence (see Morley, 2015 for a review). Given that mindfulness and self-compassion seem to act upon the SN and the closely interconnected DMN and the ECN, perhaps mindfulness and self-compassion can lead developmental changes that reduce aggression.

5. Limitations

While informative, this study has some limitations. One potential limitation of this study relates to the use of structural data in the model. Using structural data to measure brain networks has considered controversial by some, although evidence suggests that structural covariance within brain networks is associated with synchronized developmental changes (Alexander-Bloch, & Giedd, 2013). Because structural data does not show a direct link to brain activation, future research is necessary to cross-validate the finding that the relationship between perceptions of hostility and aggression is mediated by SN activity using fMRI data, which would allow for the examination of how the functional activity of the SN is related to perceptions of hostility and aggression. Combined with findings from studies using structural data like the current study, as well as research on neuroplasticity, the use of functional data would allow researchers to make more accurate inferences regarding relationships between the SN, perceived hostility, and aggression. A related concern is the reliance of the current study on correlational information. While SEM can model cause, it does not establish a cause. Future studies should consider more rigorous study design to capture causality, such as an intervention study targeting perceived hostility.

Given that brain network structure is associated with developmental changes (Alexander-Bloch & Giedd, 2013), future studies should continue to investigate the link between these synchronized changes due to development and structural changes in the brain. The use of longitudinal designs could help to clarify the involvement of perceived hostility and aggression in the structural development of networks like the SN that have been associated with aggressive tendencies.

A final limitation relates to the perceived hostility and aggression variables in this study. Both these variables were assessed using self-report, which are susceptible to fabrication and bias (Howard & Dailey, 1979; Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). While there is no apparent reason to suspect that the subjects in this study fabricated on either of these items, the possibility of response biases due to self-report is still a concern. Future studies should consider alternative methods of measuring aggression and perceptions of hostility that are not self-report.

In conclusion, the current study used SEM to determine if the surface area of SN mediated the relationship between perceptions of hostility and aggression and found that surface area provided an adequate fit of the data, suggesting that the SN mediates the relationship between these two variables. However, future research is required to further clarify the role of the SN, as well as that of other networks like the DMN and ECN, in both perception of hostility and aggression.

In conclusion, the results of this paper demonstrate a that the SN mediates the relationship between perceptions of hostility and aggression. These findings support previous findings that link the SN to aggression, aggression to perceptions of hostility, and the SN to threat evaluation. Given the convergence of these results with previous findings, researchers should consider investigating interventions that target the SN and perceptions of hostility.

Compliance with Ethical Standard

Disclosure of potential conflicts of interest: We do not have any conflict of interest to disclose.
Research involving Human Participants and/or Animals: Not Applicable, this study is based on archival data.
Informed Consent: Not Applicable, this study is based on archival data.

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