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Rumination and the Default Mode Network (DMN): A Brain Network Review

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Abstract

Rumination is one of the most common repetitive negative thinking patterns and described as a pathological structure that involves focusing negatively on the past events and their consequences. Two subtypes of rumination are defined, while *brooding* is considered as an unsuccessful problem-solving attempt focusing on the consequences of depressive symptoms, *reflection* is considered as a relatively successful problem-solving attempt focusing on the causes of the depressive state. Within the last decade, rumination has been studied by its connection with the activity of the Default Mode Network (DMN), which is known as a structure that connects specific brain regions that increase their activity during the resting state (rs) and was associated with self-referential thinking, memory and mind wandering. Additionally, a few recent studies suggest that besides the activity within the DMN, some networks working simultaneously with the DMN may also play a significant role in rumination. Therefore, five rs-fMRI (resting state functional magnetic resonance imaging) articles assessing the relationship between rumination and DMN are discussed in this study. These studies show that while the communication of some DMN subsystems are increased during the process of ruminative thinking, some subsystems of DMN seems to communicate less. Moreover, some evidence suggests that DMN synchronization might be impaired in high-trait ruminators. Finally, it has been tried to emphasize the points and suggestions that are valuable for future studies.

Key Words: rumination, brooding, reflection, negative thinking pattern, f-MRI, default mode network

Ruminasyon ve Varsayılan Mod Ağı (DMN): Bir Beyin Ağı İncelemesi

Özet

Ruminasyon, en yaygın tekrarlayıcı olumsuz düşünme örüntülerinden biridir ve geçmiş olaylar ile bunların sonuçlarına olumsuz bir şekilde odaklanmayı içeren patolojik bir yapı olarak tanımlanır. Ruminasyonun iki alt tipi tanımlanmıştır; kara kara düşünme, depresif semptomların sonuçlarına odaklanan başarısız bir problem çözme girişimi olarak kabul edilirken yansıtma, depresif durumun nedenlerine odaklanan nispeten başarılı bir problem çözme girişimi olarak kabul edilir. Ruminasyon, son on yılda, kişi dinlenme halindeyken etkinleşen belirli beyin bölgelerini birbirine bağlayan ve kendine yönelik düşünme, hafıza ve dalgınlık ile ilişkilendirilmiş

bir yapı olarak bilinen Varsayılan Mod Ağı (DMN) ile güçlü bir bağlantı göstermiştir. Ek olarak, son zamanlarda yapılan birkaç çalışma, DMN içindeki etkinliğin yanı sıra, DMN ile eş zamanlı çalışan bazı ağların da ruminasyonda rol oynayabileceğini ortaya koymaktadır. Ruminasyon ve DMN arasındaki ilişkiyi gösteren beş rs-fMRI (resting state functional magnetic resonance imaging) makalesi incelenmiş ve sonuçlar özetlenmiştir. Çalışmalardan elde edilen veriler, ruminatif düşünme sürecinde bazı DMN alt sistemlerinin iletişimlerinin artarken, bazı DMN alt sistemlerinin daha az iletişim kurduğunu göstermektedir. Ayrıca, bazı kanıtlar, yüksek ruminatif düşünce stiline sahip kişilerde DMN senkronizasyonunun bozulmuş olabileceğini düşündürmektedir. Son olarak ileride yapılacak çalışmalar için değerli olan hususlar ve öneriler vurgulanmaya çalışılmıştır.

Anahtar Kelimeler: ruminasyon, kara kara düşünme, yansıtma, olumsuz düşünme örüntüsü, f-MRI, varsayılan mod ağı

Introduction

Repetitive negative thinking pattern is the mechanism that has been examined considerably in the literature since the 2000s and has been shown among the causes of many psychiatric pathologies (Ehring & Watkins, 2008). Ways of thinking such as rumination, worry, unsuccessful problem-solving attempts of thinking and mind wandering have been recently noted in repetitive negative thinking patterns (Verkuil et al., 2009). While worry is often evaluated as the differential mindset of *Generalized Anxiety Disorder (GAD)*, rumination is the hallmark of Major Depressive Disorder (DSM-V; American Psychiatric Association, 2013).

Rumination is one of the most common repetitive negative thinking patterns and described as a pathological structure that involves focusing negatively on the past events and their consequences (Nolen-Hoeksema et al, 2008). It is noteworthy that people who ruminate often state that they feel very awful but are doing nothing to change it (Nolen-Hoeksema, 1991; Lyubomirsky et al, 1998). Ruminative thinking, which is associated with depressive symptoms in the literature, is also considered as a risk factor for depressive relapse in remitted patients (Nolen-Hoeksema et al., 2008). In addition, the fact that women report higher levels of rumination than men, raise the question of whether gender plays a role in this process of negative thinking (Johnson & Whisman, 2013).

Two subtypes of rumination are defined, while *brooding* is considered an unsuccessful problem-solving attempt by focusing on the consequences of depressive symptoms, *reflection* is considered a relatively successful problem-solving that attempts focusing on the causes of the depressive state (Treynor et al, 2003). There are also studies claiming that brooding increases the probability of relapse through worsening depressive symptoms due to its passive content (Lyubomirsky et al., 2015; Jacobs et al., 2016). On the other hand, several studies have shown that reflective rumination is no longer associated with depressive symptoms when reflection and self-awareness features are combined (Brennan et al, 2015). Related findings support that reflective rumination is a positive coping mechanism for some individuals (Lois & Wessa, 2016; Satyshur et al., 2018; Jacob et al., 2020). To summarize, while brooding subtype of rumination is considered as a more passive coping mechanism, reflective rumination is considered as a more active problem-solving skill.

In addition to cognitive and behavioral findings, the mechanisms behind the ruminative thinking are also investigated using various brain imaging techniques. Within the last decade, many studies pointed to the connection of aberrant Default Mode Network (DMN) activity pattern and rumination. The DMN is a functional structure that connects specific brain regions that tend to increase their activity when a person is in the resting state (Shulman et al., 1997; Reichle and Snyder, 2007) and was therefore associated with mind wandering, self referential thinking and memory (ref). Indeed, some studies argued that the DMN is the main structure that supports rumination (Zhou HX et al. 2019). Also, the rational for conducting Resting State Functional Magnetic Resonance Imaging (rs-fMRI) studies and their gradually increase in recent times lies in the idea that the actual rumination processes are thought to be activated when the person is left alone without ny disturbance (Hamilton et al., 2011). In general, the rs-fMRI is an ideal method for exploring synchronous activity of neural networks that are composed of brain regions located at different anatomical areas. The DMN consists of the medial prefrontal cortex (mPFC), ventral anterior cingulate cortex (vACC), precuneus, posterior cingulate cortex (PCC) and bilateral angular gyri (Buckner et al., 2008). These brain regions, which are responsible for tasks such as self-referential processing, autobiographical memory, and social cognition processes, seem to be quite compatible with ruminative thinking. However, recently a few studies reveal findings that besides the activity within the DMN, some networks working simultaneously with the DMN may play a role in rumination. These networks are the Salience Network (SN), which may be related with negative biased thoughts (Ordaz et al., 2016) and the Executive Control Network (ECN) that might relate with negative self-referential thinking process (Southworth et al., 2017).

Overall, rs-fMRI studies often demonstrate a strong relationship between DMN and rumination. In addition, high-trait ruminators are found to have stronger functional connectivity within the DMN than low-trait ruminators (Hamilton et al., 2011). Additionally, there is some evidence that high-trait rumination also have a greater activation within the SN and ECN (Kuhn et al., 2014). Since ruminative thinking is especially known for its uncontrollable and disruptive nature, rs-fMRI studies seem to present reliable measures in showing real-time activated brain regions. To summarize, the present study aims to summarize the findings of five recent rs-fMRI studies that matched the scope of the present review and are thought to fill the gaps in the relevant literature.

Method

In order to determine the studies to be discussed for this work, PubMed, Google Scholar, PsychINFO and ScienceDirect databases were used. The used keywords were: rumination, brooding, reflection, negative thinking, rs-fMRI, fMRI, default mode network, salience network and executive control network and certain combinations of these words were used in the search. While it is aimed to include up-to-date research in the present study, it was decided that the time interval should not be kept too narrow as there are few articles on brooding and reflective rumination. Therefore, articles published between the year of 2016 to 2020 were included to the study. While four of the ten related articles obtained from databases were excluded due to the use of task-based fMRI, one article was excluded from the study because it has not been published yet. Finally, it was decided to include 5 articles in total. Detailed information about the research included in the study is presented in Table 1.

Results

There was no significant difference in the socio-demographic characteristics of the participants in any research that took place in this paper, indicating that the accuracy of the comparison between the groups was high. As expected, the rumination levels of Major Depressive Disorder (MDD) patients were found to be higher in most studies compared to the healthy control groups (Lois & Wessa, 2016; Satyshur et al., 2018; Jacob et al., 2020) Similarly, no significant result was found between girls and boys in terms of brooding, reflective rumination and depressive symptom levels (Ordaz et al., 2017).

Considering the relationship between rumination and DMN, research results have shown that the connectivity between some DMN sub-systems decreases while the others increases (Lois & Wessa, 2016; Ordaz et al., 2017; Zhu et al., 2017; Satyshur et al., 2018; Jacob et al., 2020) For instance, in one study increased ruminative thinking in healthy adults was found to be associated with low connectivity within the anterior DMN and increased functional connectivity between anterior and posterior DMN (Lois & Wessa, 2016). Besides, functional connectivity was significantly decreased in remitted depression patients between dorsal ACC and thalamus and basal ganglions. Another study showed that, the connectivity within the Dorsal Medial Prefrontal Cortex (dMPFC) was increased in MDD patients, while the connectivity between dMPFC and Medial Temporal Lobe (MTL) was also increased but not the midline core and dMPFC or midline core and MTL interactions (Zhu et al., 2017). Depressed participants also showed decreased functional connectivity between Posterior Cingulate Cortex (PCC) and right middle frontal gyrus (rMFG) (Satyshur et al., 2018). The right precuneus node strength however was found to be negatively correlated with the total rumination scores in MDD patients which indicates lower connectivity between precuneus and other brain regions in MDD (Jacob et al., 2020). Besides, greater rumination tendency was found to be associated with decreased effect of precuneus on the left Medial Orbitofrontal Cortex (MOFC) which indicates an abnormal connectivity between these two DMN regions. Overall, in this study higher rumination levels were found to be associated with higher DMN entropy levels in both MDD patients and healthy controls (Jacob et al., 2020).

With regarding the brooding and reflective rumination results, one study showed that brooding type of rumination was associated with decreased functional connectivity between left amygdala and right temporal pole, while reflective rumination was found to be associated with increased functional connectivity between mPFC and posterior cingulate (Satyshur et al., 2018). Besides, reflective rumination was found to be associated with decreased functional connectivity between PCC and anterior cingulate, mPFC and left-right occipital poles. A stronger association was noted between Anterior Cingulate Cortex (ACC) and the right supramarginal gyrus (rSMG) regarding the reflective rumination (Satyshur et al., 2018). Another study has shown that, in females greater brooding type of rumination was associated with increased coherence in Salience Network (SN), additionally brooding found to be mediated the relationship between SN and depressive symptoms in females Ordaz et al., 2017).

Table 1. Detailed Information on the Research Included in the Study

Article Name	Date	Writers	Journal Name	Scales	Findings
Differential association of default mode network connectivity and rumination in healthy individuals and remitted MDD patients	2016	Giannis Lois and Miche` le Wessa	Social Cognitive and Affective Neuroscience doi:10.1093/scan/nsw085	-Beck Depression Inventory (BDI) (Beck et al., 1974) -Hamilton Depression Rating Scale (Hamilton, 1960).	*Higher level of rumination in MDD patients *Decreased FC within the anterior DMN *Increased FC between the anterior and posterior DMN
Ruminative brooding is associated with salience network coherence in early pubertal youth	2017	Sarah J. Ordaz, Joelle LeMoult, Natalie L. Colich, Gautam Prasad, Madeline Pollak, Morgan Popolizio, Alexandra Price, Michael Greicius, and Ian H. Gotlib	Social Cognitive and Affective Neuroscience doi: 10.1093/scan/nsw133	-Rumination Response Scale-Adolescent Version (RRS-A) (Burwell and Shirk, 2007)	*Sex moderate the rel. between brooding and SN in girls *Brooding mediate the rel. between SN and dep. Symptoms in girls
Rumination and Default Mode Network Subsystems Connectivity in First-episode, Drug-Naive Young Patients with Major Depressive Disorder	2017	Xueling Zhu, Qiuling Zhu, Huaizhen Shen, Weihua Liao & Fulai Yuan	Scientific Reports doi:10.1038/srep43105	-No Scale	*Increased FC between dMPFC and MTL *But not between the midline core and dMPFC or MTL
Functional connectivity of reflective and brooding rumination in depressed and healthy women	2018	Maureen D. Satyshur & Elliot A. Layden & Jennifer R. Gowins & Angel Buchanan & Jacqueline K. Gollan	Cognitive, Affective, & Behavioral Neuroscience https://doi.org/10.3758/s13415-018-0611-7	-Inventory of Depressive Symptomatology -Clinician Rated (IDS-C) (Rush et al., 2000) -Ruminative Response Scale (RRS) (Treynor et al., 2003)	*Decreased FC between left amygdala right temporal pole in brooding *Increased FC between ACC and rSMG in reflection
Neural correlates of rumination in major depressive disorder: A brain network analysis	2020	Yael Jacoba, Laurel S Morrisb, Kuang-Han Huanga, Molly Schneider, Sarah Rutter, Gaurav Verma, James W Murrough, Priti Balchandania	NeuroImage: Clinical 25 https://doi.org/10.1016/j.nicl.2019.102142	-Montgomer Åsberg Depression Rating Scale (MADRS) (Montgomery and Asberg, 1979) -Ruminative Responses Scale (RRS) (Treynor et al.,2003).	*Decreased precuneus strength in MDD patients *Higher DMN entropy levels in high-trait ruminators

Discussion

The importance of the current review study relies in the coverage and discussion of overlapping and complementary findings regarding the relationship between DMN activity pattern and rumination. Firs of all, the assessed studies indicate that changes in the DMN activity are not homogenous among the different anatomical regions. While some research has shown that the connectivity between some DMN sub-systems decreases, other studies point to increased connectivity of some regions related to rumination (Lois & Wessa, 2016; Ordaz et al., 2017; Zhu et al., 2017; Satyshur et al., 2018; Jacob et al., 2020). Secondly, Posterior Cingulate Cortex (PCC) and precuneus have been found to show abnormal relationships with other DMN sub-regions in individuals prone to rumination (Lois & Wessa, 2016; Satyshur et al., 2018; Jacob et al., 2020). Lastly, DMN has been found to be less integrated overall in rumination, meaning that DMN synchronization might be impaired in high trait ruminators (Lois & Wessa, 2016; Satyshur et al., 2018; Jacob et al., 2020).

Medial Prefrontal Cortex (mPFC) and Ventral Anterior Cingulate Cortex (vACC) are known to be key brain regions in depression, and the main functions of these regions include self-referential processing (Johnson et al., 2009). The low functional connectivity within the anterior DMN was found to be related with rumination levels (Lois & Wessa, 2016), however the strong interaction between anterior and posterior DMN in depressed participant was also detected. These results may be related to reflective rumination, which is a more adaptive subtype of rumination because the relationship between these two DMN structures is generally expected to decrease in the brooding type of rumination (Lois & Wessa, 2016; Satyshur et al., 2018; Jacob et al., 2020).

When the findings regarding the communication of other DMN regions are examined, there is an increased functional connectivity within the precuneus in contrast a decreased functional connectivity between precuneus and other brain regions (Jacob et al., 2020). This may be since precuneus is a very active structure during resting state and is associated with tasks such as self-referential thinking, imaging and autobiographic memory processing (Cavanna & Trimble, 2006). In contrast, decreased functional connectivity of precuneus with other brain regions in high-trait ruminators may indicate impaired synchronization of this structure (Jacob et al., 2020). Besides, the increased functional connectivity between dMPFC and MTL subsystems may be related with the increased rumination that includes a negative content (Zhu, Zhu, Shen, Liao & Yuan, 2017). It is known that these two regions are responsible with the understanding others' mood, social reflection and expressing negative emotions (Northoff & Bermpohl, 2004). For this reason, the fact that these two structures are in an active relationship in MDD patients raises the question of whether the content of thought towards itself is negative.

When we inspect the results related to reflection (adaptive) and brooding (maladaptive) in more detail, it is seen that the functional connectivity between DMN subsystems are often more disturbed in brooding copared to reflection (Ordaz et al., 2017; Satyshur et al., 2018; Jacob et al., 2020). While brooding was found to be related with decreased connectivity between left amygdala and right temporal pole, this result may be associated with self-critical and threatening interpretations of emotional stimuli (Satyshur et al., 2018). It can be concluded that there is a negative thought content since the brooding subtype of rumination is related to negative self-criticisms and these two brain regions are responsible in the tasks of memory processing and emotion regulation.

On the other hand, the reflective type of rumination was found to be related with a strong connectivity between the ACC and the right Supramarginal Gyrus (rSMG) (Satyshur et al., 2018). This may be related with empathy, reward and self-other distinction roles of these two regions. Hence, increased functional connectivity between the ACC and rSMG may be due to a process of examining negative thoughts and emotions about the self from a more neutral or others viewpoint.

Conclusion

There are many things to discover about functional connectivity between DMN systems when various types of rumination are activated. Nevertheless, this review points the aberrant activation of the precuneus and the impaired connectivity of DMN with other brain regions, especially in maladaptive rumination. In addition, it is known that increased functional connectivity in regions such as mPFC and ACC may be related to negative self-criticism or negative personal citations during rumination. According to these results, rumination seems to be particularly associated with biased self-related information processing, the inability to control negative emotions and negative self-perception.

However, there are many points that need to be clarified regarding the functional connectivity, which can vary according to the content of the negative thought and active-passive rumination subtypes. Future studies may prefer to achieve a more controlled order by including the task-based fMRI method to the research, especially by focusing on the connectivity of PCC and precuneus during the rumination.

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