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Neural and behavioral mechanisms of autobiographical memory and emotion regulation in borderline personality disorder and major depressive disorder

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Abstract

Major depressive disorder (MDD) is one of the most frequently diagnosed mental disorders, affecting ~4.4% of the world's population. Patients with MDD experience multiple cognitive and affective symptoms, such as prolonged diminished mood, disturbed self-beliefs, problems with autobiographical memory, and difficulties with emotion regulation. Borderline personality disorder (BPD) is one of the most diagnosed personality disorders, which affects ~1.6% of the general population. BPD is characterized by, for example, diminished impulse control, identity disturbance, and high emotional reactivity. People with BPD also face difficulties in emotion regulation and autobiographical memory. Despite frequent co-occurrence of MDD and BPD they are rarely studied together and compared to each other, especially using neuroimaging methodology. The main goal of the dissertation was to investigate the differences and similarities between MDD and BPD in autobiographical memory and emotion regulation processes at behavioral and neural levels.

The present dissertation describes a functional magnetic resonance imaging (fMRI) study comprised of two tasks, carried out with three groups of women: diagnosed with MDD, diagnosed with BPD, and healthy control (HC). The first task regarded autobiographical memory, in which participants were asked to recall sad and happy memories and to rate their emotional state during recall and vividness of the memories. Second task regarded emotion regulation, in which pictures eliciting sadness were presented on the screen, while participants were instructed to use a cognitive reappraisal strategy (CR; to reinterpret the stimuli as more positive), or a mindful acceptance strategy (MA; to be aware of one's own feelings and accept them), or to just look at them in a control condition. Additionally, they rated their emotional state during the task and their perceived success in completing it.

Considering the autobiographical memory recall task, the behavioral results only partially differentiated the groups. The MDD group experienced more sadness than the HC after the sad recall, while BPD participants experienced less happiness than HC after the happy recall. No significant differences were found between the MDD and BPD groups. The emotional autobiographical memory recall in all participants taken together led to the engagement of brain regions previously reported as crucial for this process, including the angular gyrus, supramarginal gyrus, occipital cortex, middle prefrontal cortex, insular cortex, precuneus, and amygdala. However, there were no significant differences between the groups. The functional connectivity analysis of the main effect of recall revealed significant connections between all the above-mentioned regions involved in autobiographical memory recall for all participants.

The only group difference was found between the MDD and BPD groups taken together, and the HC group. During recall of sad and happy memories, the clinical groups had a significantly stronger connection between the left precuneus and the right occipital cortex, as compared to the HC group.

In case of the emotion regulation task, the behavioral results showed that each group rated their emotional state as less sad after using either of the strategies than after passively viewing sad pictures. Moreover, ratings of emotional state were less sad after the CR regulation than after MA, even though participants rated themselves as more successful in following MA's instructions. There were no significant between-group differences in ratings of the emotional state after the strategies. Analysis of the neuroimaging data for both emotion regulation strategies taken together showed broad activations within brain regions previously associated with emotion regulation, such as the thalamus, middle cingulate, prefrontal, occipital, temporal, and insular cortices. No significant between-group differences were found. The functional connectivity analyses did not reveal any significant results.

Although the between-group results were mostly statistically insignificant, results of the autobiographical memory task indicate several group differences. The neuroimaging result differentiating the groups showed stronger functional connectivity between the left precuneus and the right occipital cortex during emotional recall in the clinical groups than in HC group. One possible explanation of this result is that in these disorders vivid autobiographical memory recall requires stronger cooperation of regions engaged in visual imagery (occipital cortex) and in recollection of contextual details (precuneus).

Streszczenie

Depresja jest jednym z najczęściej diagnozowanych zaburzeń psychicznych dotykającym około 4,4% światowej populacji. Pacjenci z depresją doświadczają wielu objawów poznawczych i afektywnych, takich jak przedłużające się obniżenie nastroju, obniżenie własnej wartości, problemy z pamięcią autobiograficzną i trudności z regulacją emocji. Zaburzenie osobowości borderline (ZOB) jest jednym z najczęściej diagnozowanych zaburzeń osobowości, które dotyka około 1,6% populacji ogólnej. ZOB charakteryzuje się między innymi zmniejszoną kontrolą impulsów, zaburzeniami tożsamości i wysoką reaktywnością emocjonalną. Osoby z ZOB mają również trudności z regulacją emocji i pamięcią autobiograficzną. Pomimo częstego współwystępowania depresji i ZOB, rzadko są one badane i porównywane razem, zwłaszcza w badaniach neuroobrazowych. Głównym celem rozprawy było zbadanie różnic i podobieństw między depresją i ZOB w zakresie pamięci autobiograficznej i procesów regulacji emocji na poziomie behawioralnym i neuronalnym.

Niniejsza rozprawa opisuje badanie z wykorzystaniem metody funkcjonalnego rezonansu magnetycznego (fMRI), składające się z dwóch zadań, przeprowadzone w trzech grupach kobiet: z rozpoznaniem depresji, z rozpoznaniem ZOB oraz w grupie kontrolnej kobiet zdrowych. Pierwsze zadanie dotyczyło pamięci autobiograficznej, w której uczestniczki miały przypomnieć sobie smutne i radosne wspomnienia oraz ocenić swój stan emocjonalny w czasie przywoływania i wyrazistość (ang. *vividness*) tych wspomnień. Drugie zadanie dotyczyło regulacji emocji - na ekranie prezentowane były smutne zdjęcia, a uczestniczki miały zastosować strategię restrukturyzacji poznawczej (reinterpretacja bodźców jako bardziej pozytywnych) lub uważnej akceptacji (bycie świadomym własnych uczuć i akceptacja ich) lub po prostu patrzeć na zdjęcia w warunku kontrolnym. Dodatkowo uczestniczki oceniały swój stan emocjonalny w trakcie zadania oraz postrzegany sukces w wykonaniu instrukcji.

Wyniki behawioralne w zadaniu pamięci autobiograficznej tylko częściowo zróżnicowały grupy. Grupa z depresją doświadczyła więcej smutku niż grupa kontrolna po smutnych wspomnieniach, podczas gdy badane z ZOB odczuwały mniej radości niż grupa kontrolna po radosnych wspomnieniach. Nie stwierdzono istotnych różnic między grupami z depresją i ZOB. Przywoływanie obu typów wspomnień, dla wszystkich badanych analizowanych łącznie, zaangażowało struktury mózgu, które już wcześniej uważano za kluczowe dla tego procesu, w tym zakrętu kątowego, zakrętu nadbrzeżnego, kory potylicznej, środkowej kory przedczołowej, kory wyspy, przedklinka i ciała migdałowatego. Nie było jednak istotnych różnic między grupami. Analiza połączeń funkcjonalnych dla efektu głównego

wspominania ujawniła istotne połączenia pomiędzy wszystkimi wyżej wymienionymi regionami zaangażowanymi w przywoływanie pamięci autobiograficznej. Jedyną różnicę międzygrupową stwierdzono między grupami z depresją i ZOB wziętymi razem a grupą kontrolną. W trakcie przywoływania obu typów wspomnień grupy kliniczne, w porównaniu do grupy zdrowej, miały znacznie silniejsze połączenie między lewym przedklinkiem a prawą korą potyliczną.

W przypadku zadania regulacji emocji wyniki behawioralne pokazały, że każda grupa oceniła swój stan emocjonalny jako mniej smutny po którejkolwiek ze strategii niż po biernym oglądaniu smutnych zdjęć. Co więcej, oceny stanu emocjonalnego były mniej smutne po reinterpretacji poznawczej niż po uważnej akceptacji, mimo że uczestniczki oceniały siebie jako bardziej skuteczne w wykonywaniu instrukcji uważnej akceptacji. Nie było istotnych różnic między grupami w ocenach stanu emocjonalnego po strategiach. Analiza danych neuroobrazowych dla obu strategii regulacji emocji wykazała zwiększoną aktywność w obszarach mózgu związanych z regulacją emocji, takich jak wzgórze, środkowy zakręt obręczy, kora przedczołowa, kora potyliczna, kora skroniowa i kora wyspy. Nie stwierdzono istotnych różnic między grupami. Analizy połączeń funkcjonalnych nie wykazały żadnych istotnych wyników.

Chociaż wyniki międzygrupowe były w większości nieistotne, wyniki zadania pamięci autobiograficznej wskazują na kilka różnic między grupami. Wynik neuroobrazowania różnicujący grupy wykazał silniejszą łączność funkcjonalną między lewym przedklinkiem a prawą korą potyliczną podczas emocjonalnych wspomnień w grupach klinicznych niż w grupie zdrowej. Jednym z możliwych wyjaśnień tego wyniku jest to, że w tych zaburzeniach przywoływanie wyrazistych wspomnień autobiograficznych wymaga silniejszej współpracy regionów zaangażowanych w wyobrażenia wzrokowe (kora potyliczna) i przywoływanie szczegółów związanych z kontekstem wydarzenia (przedklinek).

Abbreviations

AAL2	Automated anatomical labeling (atlas)
ACC	Anterior cingulate cortex
AG	Angular gyrus
AM	Autobiographical memory
ANOVA	Analysis of variance
APA	American Psychiatric Association
BOLD	Blood oxygenation level dependent (signal)
BPD	Borderline personality disorder
BPI	Borderline Personality Inventory
CES-D	Center for Epidemiologic Studies Depression (questionnaire)
CR	Cognitive reappraisal
dlPFC	Dorsolateral prefrontal cortex
dmPFC	Dorsomedial prefrontal cortex
ER	Emotion regulation
FDR	Family discovery rate
fMRI	Functional magnetic resonance imaging
FNC	Functional network connectivity
FWE	Familywise error
GLM	General linear model
HC	Healthy control
HRF	Hemodynamic response function
ICC	Intraclass correlation coefficients
IFG	Inferior frontal gyrus
MA	Mindful acceptance
MDD	Major depressive disorder
MFG	Medial frontal gyrus
MINI	MINI-International Neuropsychiatric Interview
MNI	Montreal Neurological Institute
mPFC	Medial prefrontal cortex
MTL	Medial temporal lobe
NAPS	Nencki Affective Picture System
OFC	Orbitofrontal cortex
PCC	Posterior cingulate cortex
PD	Personality disorder
PFC	Prefrontal cortex
PTSD	Post-traumatic stress disorder
ROI	Region of interest
SCID-5-PD	Structured Clinical Interview for DSM-5 Personality Disorders
SNRI	Serotonin-norepinephrine reuptake inhibitors
SSRI	Selective serotonin reuptake inhibitors
STG	Superior temporal gyrus
TPJ	Temporo-parietal junction
vlPFC	Ventrolateral prefrontal cortex
vmPFC	Ventromedial prefrontal cortex
W-PVA	World-perception-valuation-action cycle
WHO	World Health Organisation

1. State of the art

1.1. Major depressive disorder and borderline personality disorder

1.1.1. Characteristics of major depressive disorder

Depression, or *major depressive disorder* (MDD), is characterized by prolonged depressed mood, loss of pleasure from previously enjoyable activities (which is called *anhedonia*), persistent fatigability, and difficulties with concentration and motivation, among other symptoms (American Psychiatric Association [APA], 2013; World Health Organization [WHO], 1992). During a depressive episode the self-esteem is heavily reduced, and feelings of irrational guilt, hopelessness, and self-loathing appear. Moreover, previously sociable people may completely withdraw from social life and activities. Depression is also linked to very high rates of mortality due to suicide. Around 50% of the 800 000 suicide deaths per year globally occur due to a depressive episode (WHO, 2017). It is a very heterogeneous disorder and often co-occurs with other mental disorders, mainly with anxiety disorders (Kessler et al., 1996). Detailed diagnostic criteria are described in Supplementary Material 5.1.

Depression is one of the most diagnosed affective disorders. It is also one of the most diagnosed mental disorders in general and has the highest estimated prevalence among all psychiatric illnesses. The WHO reported that even 4.4% of the world's population suffers from depression (WHO, 2017), while it was estimated that 11.1-14.6% of people world-wide at some point in their lives have experienced MDD (Bromet et al., 2011). In Poland around 5% of the population suffers from depression (WHO, 2017). The disorder is regarded as one of the leading causes of disability worldwide. Due to its symptomatology MDD diminishes school and work performance, and quality of life. Moreover, it places an overwhelming economic burden on society through high workplace- and healthcare-related costs (Greenberg et al., 2003; König et al., 2019).

Previous research showed that MDD is 4 times more prevalent in women than in men (Albert, 2015; WHO, 2001, 2002, 2017). This predominance of depression in women may be influenced by interaction of hormonal and psychosocial factors, socioeconomic disadvantage, income inequality, and gender stereotypes (Albert, 2015; WHO, 2001). Women are also more likely to externalize symptoms and seek professional help. Moreover, doctors are more likely to diagnose affective disorders in women (WHO, 2001). The prevalence issue may be caused by certain gender differences and diagnostic bias, and true prevalence by gender remains unknown.

Possibly the most known psychological model of depression is the cognitive model proposed by Aaron Beck (Beck, 2008). The model consists of three aspects: negativity, cognitive biases, and dysfunctional attitudes. Firstly, the model posits that people with depression are characterized by negative thoughts and beliefs related to themselves ("I am worthless"), the world ("People are hostile''), and the future ("I won't succeed"). This negativity is also present in people's interpretations of different situations, for example "He canceled our meeting - he doesn't like me". Moreover, there is a *systematic cognitive bias*, which refers to selective attention to negative information and to blocking positive ones. The model also proposes that people with depression have dysfunctional attitudes. Beck assumed that the attitudes, for example about oneself ("Everyone leaves me"), may develop in childhood in face of adverse events (e.g., losing a parent). These attitudes are activated later in life in similar situations and cause a negativity bias (e.g., giving bigger meaning to experiences of loss). The more the attitudes are activated the more disturbed information processing becomes, leading to development of depressive symptoms. The symptoms also are negatively evaluated, closing a negative feedback loop (Beck, 2008). The relation between adverse childhood events (such as sexual, emotional, or physical abuse, neglect, or early separation from parents) and onset of depression was supported by large cohort studies (e.g., Li et al., 2016).

Clinical and scientific data shows that patients with MDD present a range of functional disturbances, both cognitive and affective. Among the cognitive impairments are disturbed attention and inhibition processes (Harvey et al., 2004). Also, throughout the literature patients with MDD perform worse than healthy control groups in verbal, working, visual (see Lee et al., 2012 for a meta-analysis), and autobiographical memory tasks (see chapter 1.2.6.). When it comes to affective disturbances, people with MDD have predominantly negative thoughts and views about themselves, other people, future, and the world (see Gotlib & Joormann, 2010 for a review of cognition in MDD). They also often experience *rumination*, i.e., goal-irrelevant, recurrent, and automatic negative thinking about themselves (Nolen-Hoeksema et al., 2008). There is also difficulty with regulating emotions (see chapter 1.3.7. for a further description).

Numerous neuroimaging studies have investigated neural processes underlying different impairments in MDD. Some authors (e.g., Ebmeier et al., 2006; Young et al., 2014) suggested that poorer memory performance in MDD may be related to hippocampal atrophy, as hippocampal volume loss in patients with MDD are widely reported (see Schmaal et al., 2016 for a meta-analysis). However, up to date only a few studies reported such a relationship (see Malykhin & Coupland, 2015 for a review on hippocampal neuroplasticity in depression).

Therefore, it was suggested that memory deficits could precede the volumetric changes (Malykhin & Coupland, 2015).

Depression has been also associated with altered activation of regions engaged in cognitive and emotional processes (Etkin et al., 2015). The frontoparietal network, involving the lateral prefrontal cortex (PFC), anterior cingulate cortex (ACC), and inferior parietal regions (e.g., Dosenbach et al., 2007) is implicated in cognitive control processes and strategic memory search (St. Jacques et al., 2011). In depression this network was frequently shown as hypoactive, i.e., with diminished activation, as compared to healthy controls. For example, lower activation of dorsolateral PFC (dlPFC) in MDD could be related to disturbed attention processes and goal-directed behavior (meta-analysis by Kaiser et al., 2015). However, the activation within the frontal regions in MDD is not homogenous among the literature. The meta-analysis by Palmer et al. (2015) showed that cognitively demanding tasks, involving memory and attention manipulations, increased activation of the middle frontal regions, while activation of the inferior frontal region was decreased. Increased activation was suggested to reflect greater effort put into a task performance (Fitzgerald et al., 2008; Palmer et al., 2015), while decreased inferior frontal activity could be related to diminished cortical inhibition (Palmer et al., 2015). Therefore, engagement of different frontal regions may depend on task demand and stimuli used.

Regions responsible for emotional processing were frequently reported as hyperactive in MDD. For example, Hamilton et al. (2012) showed in their meta-analysis that studies with negative stimuli resulted in greater activation of the limbic system regions: the amygdala, insula, and dorsal ACC. Therefore, depressed individuals may perceive negative emotional information as more salient and emotionally arousing. Depression could be also characterized with disturbed processing of positive and rewarding stimuli, through decreased activation of reward-processing regions such as the ventral striatum, ACC, and insula (e.g., Satterthwaite et al., 2015)

Depression is a common and debilitating mental disorder. Despite years of research on this condition we need further studies as there is still a lot to uncover about the disorder. A better understanding of affective-cognitive impairments in MDD, such as autobiographical recall, could offer progression of theories and may eventually contribute to available treatments.

1.1.2. Characteristics of borderline personality disorder

Borderline personality disorder (BPD) is one of the most diagnosed and researched personality disorders. A *personality disorder* (PD) is a set of deeply settled, permanent patterns of behavior and inner experience, that significantly deviates from that of an average, healthy person (APA, 2013; WHO, 1992). It develops in childhood or adolescence and continues to adulthood. The symptoms of PDs are enduring, inflexible, and stable in time. The symptoms can be manifested in cognition, affectivity, interpersonal functioning, or impulse control. They resurface in response to daily social situations, disrupting personal and social life. Personality disorders may coexist with other disorders but are not derived from them nor from brain diseases. The ICD-10 recognizes 8 types of PDs (WHO, 1992), while the DSM-5 distinguishes 10 types of PDs (APA, 2013).

BPD is characterized, among others, by diminished impulse control, affective instability, and identity disturbance (APA, 2013; WHO, 1992). The relationships that a person with BPD engages in are unstable, characterized by going from idolization of someone to hatred and isolation. In BPD the world is experienced as black and white, good or bad. BPD is also associated with high rates of self-harm and has the highest rates of suicidality among all personality disorders (Bachmann, 2018). The results of a 16-year follow-up study on BPD showed that 4.5% people with BPD died by suicide, as opposed to 1.4% people with other PDs (Zanarini et al., 2016). It is also a very heterogeneous disorder, which usually co-occurs with depression, anxiety disorders, eating disorders, substance use disorders, or other personality disorders. Detailed BPD diagnostic criteria are described in Supplementary Material 5.1.

The lifetime prevalence of BPD in the general population is around 1.6% (Ellison et al., 2018). However, BPD prevalence is higher in the clinical and treatment settings. Around 15-28% of all patients in psychiatric outpatient clinics have a BPD diagnosis (Zimmerman et al., 2008). There are reports that BPD may be even 3 times more prevalent in women than in men (Sansone & Sansone, 2011; Skodol & Bender, 2003). This could be caused by different clinical manifestations of BPD in women. Men with BPD are more often prone to severe substance abuse or present with antisocial personality characteristics which bring them to substance abuse treatments or jail, respectively, where they may be misdiagnosed. Therefore, the reported prevalence may be caused by certain gender differences in clinical representations or by a diagnostic bias. As in the case of depression, the true prevalence of BPD by gender remains unknown.

One of the leading models on BPD development is biosocial theory proposed by Marsha Linehan (1993). The model proposes that BPD is a disorder of emotion regulation, which underlies many of the symptoms. The source of BPD lies in co-occurrence of biological vulnerabilities (such as a fronto-limbic dysfunction), and unsafe, invalidating environment in which a caregiver invalidates a child's emotional reactions and does not teach adaptive regulatory strategies. Often the child also experiences neglect or abuse - emotional, physical, or sexual. In consequence an individual with BPD has heightened emotional reactivity, is unable to regulate their emotional responses, and has a very slow return to emotional baseline. In turn, they engage in various maladaptive behaviors in order to diminish negative affect, such as self-harm or substance abuse.

As the model posits, affectivity is one of the major areas of disturbance in BPD. Individuals with BPD have *alexithymia* - problems with understanding, identifying, and describing their emotion (New et al., 2012). They experience emotional instability and high emotional reactivity. They also have a negativity bias. For example, Kaiser et al. (2017) showed in their meta-analysis that people with BPD have an attentional bias towards negative and BPD-related words (e.g., regarding abandonment, rejection). Another study showed that BPD participants rated positive and neutral words as more negative, suggesting an overall negative evaluation of information (Winter et al., 2015). Moreover, functional neuroimaging studies showed that people with BPD have disturbed activation of frontal and limbic regions, such as the ACC, orbitofrontal cortex, dlPFC, hippocampus, insula, and amygdala (review by Dell'Osso et al., 2010). In response to negative emotional stimuli, there is higher activity in the limbic regions, which could suggest perceiving these stimuli as more intensive. On the other hand, frontal regions such as dlPFC and ACC show lowered activation, which could mean that during emotional processing regions involved in emotion regulation are recruited less (review by Ruocco & Carcone, 2016). These disturbances could underlie core difficulties with emotion regulation and hyperreactivity (see chapter 1.3.8. for a further description of emotion regulation in BPD).

Part of the BPD psychopathology is also formed by disturbance in processing the self. The patients have an unstable and poorly developed sense of identity. They also evaluate themselves more negatively and evaluate more events as self-related than do healthy people (Winter et al., 2017). The disturbance of processing the self and others was shown in the neuroimaging studies. In a study by Beeney and colleagues (2016) participants were asked to evaluate self and other personality traits. Participants with BPD had higher activity in the midline structures for both types of evaluations than the healthy group. These structures,

including the medial prefrontal cortex, precuneus, and posterior cingulate cortex, are typically involved in understanding the mental states of the self and others (Gunderson et al., 2018).

Borderline personality disorder is complex and difficult to treat. It causes various disturbances in daily life and has a high risk of suicide. Even though the literature on BPD is growing, more research is needed for better understanding of different components of BPD and their interaction.

1.1.3. Similarities and differences between major depressive disorder and borderline personality disorder

Major depressive disorder and borderline personality disorder share several similarities and differences. The former is a disorder of affect and the latter a disorder of personality. An episode of MDD has state-like symptoms, which usually last for several weeks and then go into remission. BPD has trait-like symptoms, which are prolonged and stable in time. Nevertheless, both disorders share some of the symptoms: heightened negative affect, negative cognitive bias, disturbed emotion regulation, dysfunctional processing of the self, and suicidal ideations (Beatson & Rao, 2013).

Both disorders often co-occur. MDD is the most frequently co-occurring disorder with BPD, affecting 61-83% of people with BPD (Gunderson et al., 2018). Patients with BPD and co-occurring MDD have high rates of additional post-traumatic stress disorder (PTSD), substance use disorders, and other PDs, more severe impairments in functioning, and a higher number of suicide attempts (Gunderson et al., 2018). They also may experience more severe depressive symptoms, higher emotional reactivity, more diverse negative affect, and greater emotional dysregulation than patients with MDD only (e.g., Dixon-Gordon et al., 2015). On the other hand, there is a depressive experience in BPD, even in the absence of co-occurring MDD. This experience is perceived differently from an individual depressive episode (Köhling et al., 2015). While depressive symptoms in MDD are prolonged and not responsive to environmental stimuli (Perez-Rodriguez et al., 2018), BPD-related depressive mood is transient and situational, related to interpersonal stressors. Moreover, these depressive symptoms do not respond to pharmacological treatment but to psychotherapy, as they are a part of personality pathology (Beatson & Rao, 2013). Sometimes it can be difficult to distinguish between depression co-occurring with BPD and BPD-related transient depressive symptoms, which leads to misdiagnosis and wrong course of treatment (Köhling et al., 2015).

BPD and MDD overlap in terms of experiencing self-directed negative emotions, which are often shame, emptiness, guilt, and hopelessness (Silk, 2010). Also, in both disorders, there is a negativity bias toward different types of information and emotional dysregulation. However, BPD patients may experience more *active* emotions such as anger or hostility (Köhling et al., 2015), and greater emotional reactivity to negative stimuli (Linehan, 1993), while in comparison people with MDD may have a rather blunted response to those (meta-analysis by Bylsma et al., 2008).

Previous neuroimaging studies showed that in BPD and MDD there is a dysfunctional activation of the prefrontal cortex and hyperactivation of the amygdala when processing negative stimuli (e.g., Drevets, 2007; Herpertz & Bertsch, 2014; Schulze et al., 2016). A recent meta-analysis by Schulze et al. (2016) compared studies on affect processing in BPD, MDD, and PTSD in comparison to healthy control groups. They showed that in response to negative stimuli people with BPD had higher activation of the amygdala, hippocampus, temporal regions, middle PFC (mPFC), and lower activation of the postcentral gyrus than the healthy participants. When compared to controls, MDD patients had higher activation of the insula and decreased activation of the amygdala, temporal, and parietal regions. The result of the diminished amygdala activity was at odds with previous meta-analyses and theories, and the authors suggested that different methodological approaches were the cause. A comparison of BPD and MDD groups revealed that BPD patients had higher activation of the amygdala, hippocampus, angular gyrus (AG), and inferior frontal gyrus (IFG). This result could be related to higher emotional reactivity in BPD. The MDD group had increased activations of the parietal cortex, premotor cortex, and the postcentral gyrus. The diminished activation of these regions in BPD could be related to increased impulsivity and decreased cognitive control. The issue with the studies used in that meta-analysis is that none compared MDD and BPD directly, and so these results may otherwise be inaccurate.

Despite MDD and BPD often co-occur, and despite rich literature on these disorders, relatively few studies compared them directly. The knowledge about what is unique for either of these disorders is inconsistent and requires further research. Broadening our understanding of the relationships between BPD and MDD could help in improving the diagnostic process and available treatments.

1.2. Autobiographical memory

1.2.1. Introduction to autobiographical memory

Most people can remember places they visited, people they met, first kiss or a first date, that embarrassing moment which happened in high school, losing somebody, or buying a new car. All the events that we lived through are stored in autobiographical memory (AM). It is believed that AM integrates episodic knowledge with semantic memory (a review by Cabeza & St Jacques, 2007). Episodic memory contains information about personal events that happened in a specific time and place, and semantic memory stores facts and knowledge about oneself and the world. According to Tulving (2002) autobiographical memories are meaningful to the self and their recollection is characterized by *autonoetic awareness* - a conscious sense of time, of possessing a memory of an experience and re-living it through a mental time travel to the past (Tulving, 2002). The feeling of re-experiencing a past event is possible due to feelings of vividness and rich contextual, emotional, and sensory details that the memory often contains. In this chapter I characterize AM from the theoretical point of view, then I briefly describe certain research methods used in this field and the neural underpinnings of AM recall. The abbreviation "AM" will be used when mentioning the whole autobiographical memory system and the abbreviation "AMs" will be used when mentioning autobiographical memories.

Autobiographical memory develops in childhood through early experiences and relationships with parents or caregivers (Fivush et al., 1996). For example, parents provide an elaboration of the child's experience and provide a more complex narrative of what happened. The child has more opportunities to talk about and to recall events. These parent-child interactions later influence development of the child's sense of self (Çili & Stopa, 2019, Chapter 1).

Proper development of AM is crucial for different areas of daily functioning. It serves many different functions but the most recognized in the literature are directive, self, and social functions (Bluck & Alea, 2002; Bluck et al., 2005). The *directive function* of AM plays a role in guiding attention, behavior, and emotions to and from different situations or information. Previous experiences have an impact on future goals, plans, and behavior, help in solving current problems, and in avoiding adverse events (Çili & Stopa, 2019, Chapter 1). The *self-function* relates to the importance of AM for the self. There are some inconsistencies when it comes to defining the concept of "self". However, relying on main theories, the self is generally viewed as a psychological construct that includes attributions and beliefs about oneself, own goals, social roles, and past experiences (James, 1890; Morf & Mischel, 2012). Properly

developed AM plays a role in the development and maintenance of identity and a coherent sense of self. Own memories are used to develop an integrated narrative of one's life story. This story is about one's past and present and contains a perception of one's future. Such a narrative gives one's life a direction and preserves psychological well-being (McAdams & McLean, 2013). In turn, properly developed identity is relatively stable throughout one's life and may serve as a resilience factor against the development of various psychological disorders. Finally, the *social function* of AM plays a role in developing interpersonal relationships through sharing narratives of personal experiences with others (Bluck et al., 2005).

Some researchers suggested that AM not only serves those three functions but possibly a broader spectrum (see Harris et al., 2014 for their investigation of different functions). One such theorized additional function may be the *emotion regulation function* (Harris et al., 2014; Joormann & Siemer, 2004; Pasupathi, 2003). In several studies, healthy non-clinical participants were induced with a sad mood and were asked to describe what kind of memories they could recall. Even though at first, they retrieved negative AMs, later they started recalling more positive memories (e.g., Foland-Ross et al., 2014; Josephson, 1996; Öner & Gülgöz, 2018), which significantly improved their mood (Joormann & Siemer, 2004). Some participants even reported that positive recall was intentional in order to feel better (Josephson, 1996). These results suggest that recall of positive AMs may be a successful way of regulating emotions in healthy people but not in clinical samples, for example in dysphoric patients (Joormann & Siemer, 2004). Attention processes in these patients may be guided too extensively towards negative experiences and in turn, they may activate ruminative processing (see the next chapters for AM characteristics in MDD and BPD). The results showing positive AM recall after negative mood induction stand against a known cognitive phenomenon called *a mood-congruency effect* (Blaney, 1986). This effect can be observed when information similar in valence to our current mood is more attended to, is easier to be remembered, and to be retrieved. Some of the AM studies have shown that after a positive mood induction, participants recalled more positive AMs than negative ones. When a negative mood was induced, more negative AMs were retrieved (e.g., Rusting, 1999). These inconsistencies in findings of incongruent or congruent effects may arise from individual differences such as certain personality traits or mental health.

The *self-memory system* is a conceptual framework describing AM and its relationship with the self (Figure 1; Conway, 2005; Conway et al., 2004; Conway & Pleydell-Pearce, 2000). This framework suggests that AMs are *constructed* (i.e., retrieved) based on representations from *the autobiographical knowledge base* and their interaction with *the working self.* The

autobiographical knowledge base involves autobiographical knowledge and episodic memories. The content of this knowledge may range from highly abstract to highly specific information. The most abstract level is called *the life story*, which contains general knowledge about the self and can be divided into different life periods (for example "working at company X"). The life periods can be divided into different general life events (e.g., "the first week of work"), which in turn provide access to the most specific episodic memories (e.g., "meeting the co-workers"). The working self is viewed by the authors as composed of different goals, self-images, values, and beliefs. Its relationship to autobiographical knowledge is bi-directional. On the one hand, the working self is shaped by and modified in order to be consistent with autobiographical knowledge. On the other hand, in order to maintain coherence of the current goals and self-views, the working self-influences accessibility of that knowledge and memories. For example, past experiences shaped a self-belief of being successful. Therefore, retrieval of memories of success may be facilitated while memories of failure may be modified or inhibited.

In terms of the self-memory system, retrieval of AMs starts with the appearance of a cue (Conway, 2005). It can be any stimulus such as a sound, taste, smell, feeling, or thought. The autobiographical knowledge is then being searched for information connected to that cue. For example, a certain smell can access a life period "marriage". When that information is found the cue can be elaborated upon and then a new cycle of search-and-elaboration begins, accessing different general life events (e.g., "honeymoon", "every anniversary"). When the sought-for information is finally activated a specific episodic memory is accessed, which contains vivid imagery (e.g., "day of the wedding"). Therefore, the AM retrieval process could be divided into two phases. The early stage is in the literature sometimes referred to as the initial search phase (Cory S et al., 2018). It involves a controlled search for a specific memory based on a presented cue. During the second stage of AM retrieval, the constructed memory is held in mind and elaborated upon through retrieval of various contextual and sensory details.

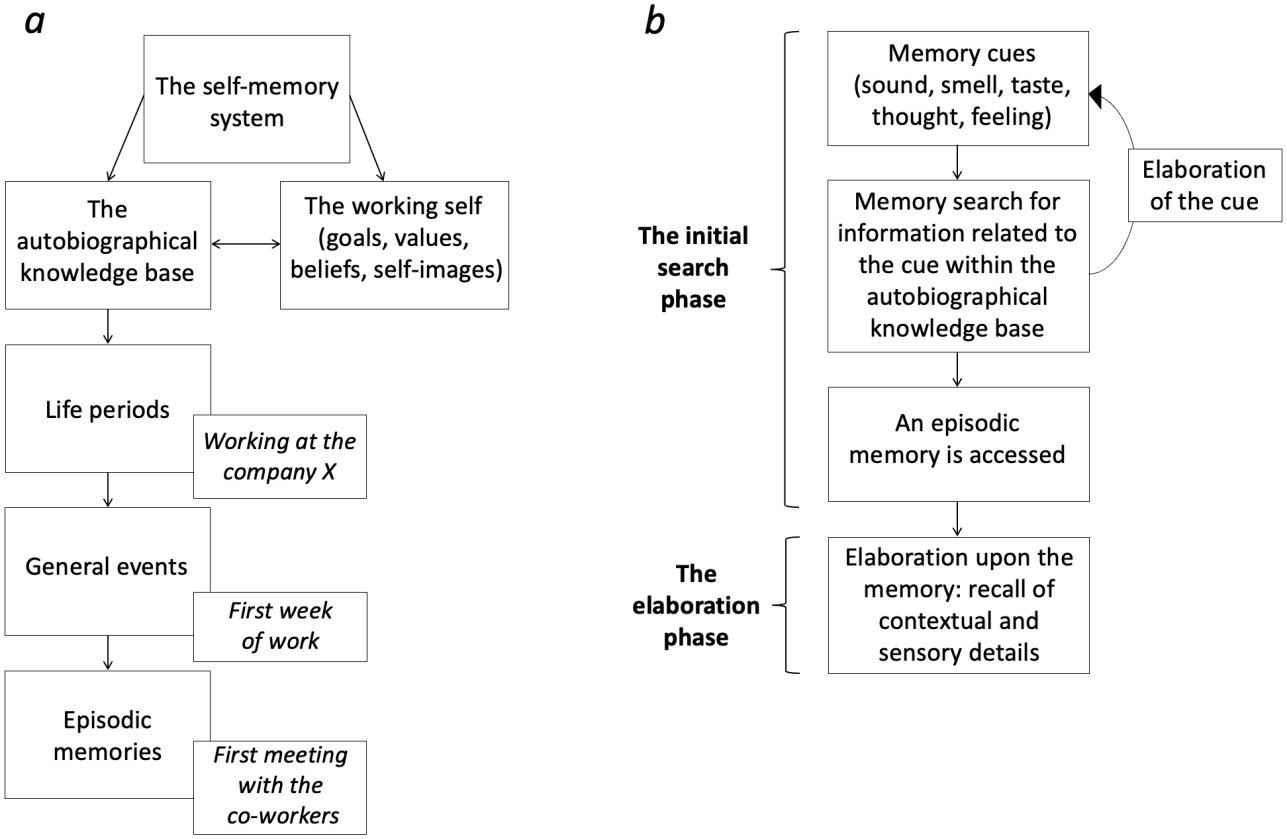


Figure 1. The self-memory system. (a) The hierarchical structure of the system. (b) Overview of the process of autobiographical retrieval within the system's framework. Based on Conway, 2005; Conway et al., 2004; Conway & Pleydell-Pearce, 2000.

This division of AM retrieval into two phases has been frequently used in neuroimaging studies. The results of those studies are described in the following section.

1.2.2. Selected aspects of research paradigms in autobiographical memory studies

There are several approaches to studying AM depending on the research goals. The construction of a task may differ depending on whether the purpose of a study is to compare different phases of the AM retrieval or to study it as a whole; to compare differently valenced AMs or memories derived from different life periods. Research studies also differ based on the study groups, comparing, for example, different age groups, or healthy individuals to clinical populations. There are several methodological challenges in studying AM retrieval, due to complexity of the AM. The content and accuracy of AMs are difficult to verify. Memories also vary on many properties that can be difficult to control, such as vividness, emotionality, arousal

or remoteness. I will focus on two methodological aspects: cueing methods and selection of control tasks for neuroimaging studies.

Autobiographical memories are naturalistic stimuli. They are personal experiences that reflect the real life of the participants and the real-world conditions. Therefore, AMs provide higher ecological validity of a study than stimuli memorized in a laboratory setting (Cabeza & St Jacques, 2007; St. Jacques, 2012). However, as they are not a set of stimuli prepared beforehand in a laboratory, their content may be difficult to control. In order to maintain some level of control over the properties of AMs the studies mainly rely on voluntary retrieval, which is prompted by a cue (Cabeza & St Jacques, 2007), even though the retrieval is often involuntary in real-life situations (Berntsen & Hall, 2004). There are various types of retrieval cues that are used across the literature which have different levels of retrieval effectiveness and interference in memory's content (Cabeza & St Jacques, 2007). Generic cues relate to general words (e.g., "house", "birthday"), either neutral or emotional, which are supposed to generate unrehearsed and spontaneous memories but there is little control over the retrieved material. Another approach uses an interview before the main experiment, during which a participant is asked about memories of specific content or emotionality and the cues are constructed based on these descriptions. This method gives greater control over the memory content but poses a risk of memories being rehearsed or recalled from the interview perspective. The memory cues may also be generated by the family or friends of a participant but there is a risk that the participant will not understand which memory the cue refers to.

The neuroimaging field is faced with other issues such as designing a proper control task. Kim (2012) noticed that AM relies mainly on memory and self-referential components and that different control tasks influence the difficulty of distinguishing between these components. Kim described four types of control tasks most often used in AM studies: non-memory tasks (such as odd-number detection), semantic memory tasks (e.g., sentence completion), long-term memory tasks, resting baseline.

The procedures and control tasks may vary depending on specific research questions. Therefore, experimental paradigms may for example compare emotional vs neutral memories, positive vs negative, or remote vs recent events. The present dissertation focuses on emotional AMs and their neural underpinnings are described below.

1.2.3. Overview of the neural underpinnings of autobiographical memory recall

Despite variability across studies of AM the neuroimaging field helped in establishing core brain regions involved in AM retrieval which are sometimes referred to as the AM retrieval network. In general, the network involves the PFC, temporal cortex (including amygdala and hippocampus), parietal cortex (including temporo-parietal gyrus [TPJ] and angular gyrus), occipital cortex, and precuneus (for meta-analyses see Kim, 2012; Spreng et al., 2009; Svoboda et al., 2006, but also see Cabeza & St Jacques, 2007; Iriye & Jacques, 2018; St. Jacques, 2012). These regions typically show a left-lateralized pattern of activation during AM retrieval (Kim, 2012; Spreng et al., 2009; Svoboda et al., 2006), however during later stages of recall (which is described below), such as vivid re-experiencing (e.g., Daselaar et al., 2008) or during recall of emotional AMs (e.g., Denkova et al., 2006; Vandekerckhove et al., 2005), the activation may shift towards the right hemisphere. In the following paragraphs, I will characterize different phases of AM recall, which provides a more general overview of neural underpinnings of this memory type. Then, I will describe in more detail the main aspects of AM that are important for the present dissertation: self-reference and emotionality.

Neuroimaging studies provided a more detailed basis of AM processing, and several studies examined the neural activation during consecutive stages of AM retrieval. The initial search phase engages several brain regions, such as the medial and lateral PFC, hippocampus, and amygdala (Figure 2; Daselaar et al., 2008; Muscatell et al., 2010). The mPFC processes emotions (Phan et al., 2002) and self-referential information which is crucial for the construction of a memory (Cabeza & St Jacques, 2007; St. Jacques, 2012). The lateral PFC mediates memory search and recollection, and retrieval of semantic knowledge related to AMs, such as information about places, people, and oneself (e.g., “I like watching movies”, “Anna, my best friend, is married”; Svoboda et al., 2006). The hippocampus and parahippocampal gyrus have also been frequently reported during the initial search phase as they are involved in accessing a specific memory (Addis et al., 2004; Daselaar et al., 2008). The amygdala processes the emotional content of AMs. Its activation was previously noted during the initial search phase, even before a memory was fully retrieved (Daselaar et al., 2008). It was also found that there is increased functional connectivity between the amygdala and hippocampus during retrieval (Daselaar et al., 2008; Markowitsch et al., 2000). This suggests that recollection of emotions, which is processed by the amygdala, may enhance memory search processes performed by the hippocampus (Greenberg et al., 2005; St. Jacques, 2012).

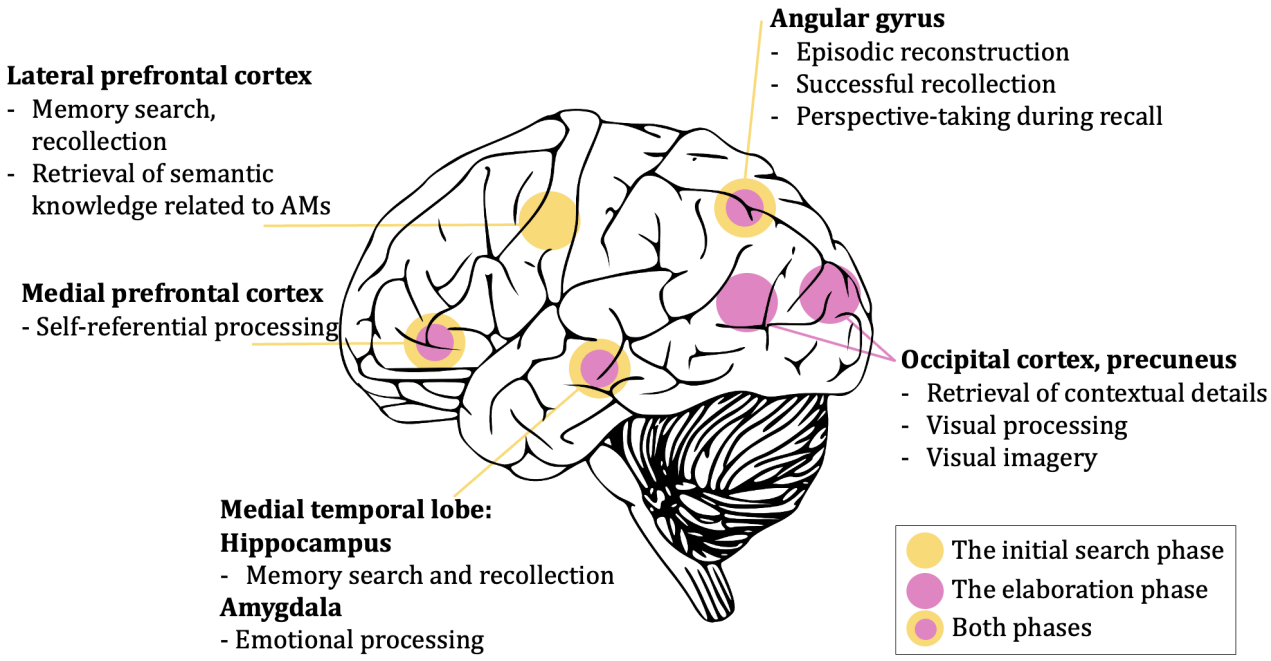


Figure 2. A general overview of the brain regions typically involved in autobiographical memory retrieval. AMs - autobiographical memories.

The later period of retrieval includes the recall of sensory details and visual imagery. During this phase higher activity was found in the occipital cortex and precuneus, regions involved in the retrieval of contextual details and in visual processing (Cavanna & Trimble, 2006; Daselaar et al., 2008; St. Jacques, 2012). Their activity was found to be positively correlated with subjective ratings of the vividness of a memory (Daselaar et al., 2008; Gilboa et al., 2004). What's important is that visual cues are not crucial for visual processing during retrieval. Activation of the occipital cortex during AM retrieval was found even in absence of visual stimulation (Daselaar et al., 2008). However, when the memories are visually cued the activation of this region raises and is co-activated with hippocampus, lateral and medial PFC, and ventral parietal cortex (which mediates attention processes), therefore suggesting that visual cues are more arousing for the retrieval process and may enhance or facilitate it (St. Jacques, 2012).

St. Jacques and colleagues (2011) found that some of the above-mentioned regions are in fact engaged during both phases of retrieval. These regions were: mPFC and its ventral part, and medial temporal lobe (MTL), ventral parietal cortex. Activation of the PFC regions and MTL in both phases may suggest that recovery of contextual details and self-relevant information can occur throughout the whole AM retrieval (St. Jacques, 2012). Other studies found that also the amygdala was active during both retrieval phases. Engagement of this region in the

elaboration phase may enhance the reconstruction of event's details, feelings of vividness, or of re-experiencing an event (Markowitsch et al., 2000; Sharot et al., 2004). Moreover, the parahippocampal gyrus was shown to play a role in the retrieval of memory details (Addis et al., 2004), and the hippocampus' activity was shown to be positively correlated with ratings of memory's vividness (Gilboa et al., 2004).

One more important brain region implicated in AM recollection processes, regardless of the retrieval phase, is the angular gyrus. It appears very often in the results of neuroimaging studies of AM and episodic recall, however, it's exact role in these processes is still unclear and is being explored. Results of several studies suggested that AG contributes to different forms of episodic reconstruction (for example, to imagining a different outcome of an event; Faul et al., 2020) and successful recollection (Rugg & King, 2018), and may be involved in processing of semantic knowledge (Humphreys & Lambon Ralph, 2015).

A study by Inman and colleagues (2018) analyzed functional connectivity and showed that early retrieval phase was characterized by stronger connections between ventrolateral PFC (vlPFC), amygdala, hippocampus, TPJ, inferior parietal cortex, and occipital cortex, while the elaboration phase mainly showed coactivation of dlPFC, mPFC, TPJ, hippocampus, occipital cortex, inferior parietal cortex, and PCC. These results are in line with previous functional whole-brain studies described above in this chapter.

Another study asked participants to freely retrieve AMs, without cueing, and used the angular gyrus as the seed region for functional connectivity analyses (Bellana et al., 2016). The left AG, relative to the right AG, showed greater connectivity with mPFC, left TPJ, and left lateral temporal cortex. The right AG showed greater connectivity with right parahippocampal and retrosplenial cortices. The authors suggested that the left AG could contribute more to the recollection of subjective aspects of a memory, while the right AG, together with the MTL, could contribute more to the objective recollection of specific details of a memory.

1.2.4. Neural underpinnings of self-referential processing in autobiographical memory

As mentioned above, relation to the self is an inherent feature of AM. Memory recall allows the self to "travel in time", relive an experience (Tulving, 2002), and reflect its impact on the current identity (Çili & Stopa, 2019, Chapter 1). Neuroimaging studies suggest that during the AM retrieval the self is mainly processed by the mPFC (for a review see Cabeza & St Jacques, 2007, for a meta-analysis see Denny et al., 2012; also see St. Jacques, 2012). This region was

already established as involved in the processing of self-referential information in general, for example during self-reflection or trait judgments (D'Argembeau et al., 2007; Muscatell et al., 2010). Greater involvement of mPFC is also visible when the AM condition is compared to non-memory or long-term memory control tasks, which do not rely on processing self-referential information (Kim, 2012). The ventral part of the mPFC may be of more interest for studying AM. In general, the vmPFC is more engaged in processing the self-related judgments, when compared to other-related judgments (Denny et al., 2012) and when information about the self is perceived as important and emotional (such as self-descriptive adjectives; D'Argembeau et al., 2012). In studies of AM, vmPFC was found to be more engaged when, for example, a memory was cued by photos from one's own life, compared to photos prepared in the laboratory (Cabeza et al., 2004) or taken from somebody else's life (Rissman et al., 2016).

Several structural and functional connectivity studies showed that the mPFC was connected to the PCC (e.g., Greicius et al., 2009). PCC is broadly engaged in the processing of self-referential information, emotions, and episodic memory (Cavanna & Trimble, 2006).

Previous studies also reported involvement of the ACC in autobiographical recall (Denkova et al., 2006; Gardini et al., 2006; meta-analysis by Svoboda et al., 2006) which, together with the mPFC and precuneus, constitutes the cortical midline structures. ACC is involved, among other functions, in perception and processing of the self (Northoff et al., 2006).

1.2.5. Neural processing of emotional autobiographical memories

Autobiographical memories may involve powerful emotional content. Emotional events are more arousing than neutral memories and therefore may be more easily encoded in memory (Talarico et al., 2004) and then more easily retrieved (Dolcos et al., 2005). Moreover, emotional AMs are more successful than neutral ones in guiding future behaviors - we learn which events are related to positive outcomes and which events should be avoided as they may be more aversive (Levine, Safer & Lench, 2006). Emotional AMs may also be more important for creating a coherent life story (review in Beike & Wirth-Beaumont, 2005) and as mentioned above, recall of positive AMs may serve as an emotion regulation strategy (e.g., Joormann & Siemer, 2004).

The main brain region recognized as involved in processing emotions related to AMs is the amygdala (Cabeza & St. Jacques, 2007; Daselaar et al., 2008; Dolcos et al., 2017; Greenberg et al., 2005; Kim, 2012; Spreng et al., 2009; Svoboda et al., 2006). Its activation was found to be

greater for events rated as highly emotional (vs events with less emotional intensity; Daselaar et al., 2008). However, some studies failed to find this relationship between amygdala activation and emotionality of AMs (e.g., Vandekerckhove et al., 2005). Dolcos and colleagues in their review of the impact of emotions on memory (2017) suggested that disparities in amygdala engagement may be influenced by different task instructions. For example, Denkova and colleagues (2013) compared two task conditions for positive and negative AMs - a condition asking to direct attention to emotional content and a condition asking to direct attention to other contextual details of a memory. Focusing on emotions was associated with higher subjective ratings of relieving a memory and with increased activation of the left amygdala.

The studies distinguishing between differently valenced emotional AMs are relatively scarce and most of them focused on the processing of positive AMs. This preference is perhaps imposed by the fact that positive memories are more adaptive, they may regulate emotions (e.g., Joormann & Siemer, 2004), and influence better psychological well-being (Speer et al., 2014). Some researchers focused on AMs valence and differentiated between positive, negative, or neutral memories. One such study was performed by Piefke and colleagues (2003) who asked participants to retrieve positive and negative memories. They found that positive AMs elicited higher activity in the mPFC, orbitofrontal cortex, temporal pole, and medial temporal cortex, whereas negative AMs elicited higher activity in the middle temporal gyrus. Another study by Speer and colleagues (2014) compared positive AMs to neutral ones. The results showed that positive AM recall increased subjective ratings of positive mood and increased activity in the striatum and mPFC. Activation of the striatum was also positively correlated with subjective ratings of the current mood. Because both the striatum and mPFC were previously linked to processing rewards (e.g., Wager et al., 2003), the authors suggested that their activation reflected a rewarding nature of positive AMs. A recent study (van Schie et al., 2019) also compared positive and neutral AMs, however it was mentioned that the focus was an ability to relive the memories rather than to recall them. Positive AMs were rated as more vivid and pleasant than the neutral AMs. There was also a positive relationship between memory vividness and reported positive mood. Reliving of positive AMs engaged the mPFC, hippocampus, insula, amygdala, ACC, precuneus, PCC, and orbitofrontal cortex (OFC). The authors also found that higher ratings of memory vividness were related to higher activation of the hippocampus, amygdala, and insula. The authors suggested that the more vivid the memories were, the more increased the processing of the self was (van Schie et al., 2019).

A few other studies compared happy AMs to memories containing other specific emotions: sadness (Markowitsch et al., 2003; Pelletier et al., 2003; Sitaram et al., 2011), or

disgust (Sitaram et al., 2011). Most of those studies had very small sample sizes (between 5 and 20 participants), differed in the cueing methods and in the number of AMs. Nonetheless, these studies showed that higher activation during retrieval of happy AMs was most consistent in the ACC, the mPFC, the temporal gyrus and temporal pole, the insular cortex, the OFC, the hippocampus, and the amygdala (see Suardi et al., 2016 for a review). The mPFC, ACC, and insula were previously linked to processing different aspects of the self (Cabeza & St. Jacques, 2007; D'Argembeau et al., 2007; Seth & Friston, 2016; St. Jacques, 2012) which may suggest that happy memories are more self-relevant or contain more information about the self. Also, higher activation of limbic regions (e.g., the insula and amygdala) during retrieval of happy memories suggests a stronger experience of feelings and possibly pleasure (Suardi et al., 2016).

To my knowledge, there are only four functional magnetic resonance imaging (fMRI) studies with healthy participants that examined sad (or negative in general) AMs. The study by Vandekerckhove et al. (2005) compared negative, stressful, positive, and neutral memories but they did not find any significant differences. Piefke and colleagues (2003) compared positive and negative memories and showed that negative AMs activated the right middle temporal gyrus. In two other studies participants were asked to recall sad and happy memories (Markowitsch et al., 2003; Pelletier et al., 2003). Comparisons between sad and happy AMs showed that sad memories engaged the lateral OFC, vlPFC (Markowitsch et al., 2003; Pelletier et al., 2003), lateral temporal cortex (Markowitsch et al., 2003), and pons (Pelletier et al., 2003). Taken together, these findings show consistent involvement of sub-regions within the orbitofrontal, prefrontal, and temporal cortices during the retrieval of negative AMs.

The AM retrieval is processed by a specific network of brain regions and the literature reviewed above shows that these activations are consistent across the literature regardless of differences in study designs. However, despite broad knowledge of AM processes in healthy populations little is known regarding the functioning of AM in various clinical samples. Studying this topic in mental disorders could be crucial for a better understanding of processing AMs in different clinical populations. The current doctoral project aimed at providing new knowledge of AM processing in depression and BPD. The next sections characterize this process in these two clinical populations.

1.2.6. Autobiographical memory in major depressive disorder

Autobiographical memories shape the sense of self and identity, help in decision making and problem-solving, and play a role in forming interpersonal relationships (Bluck & Alea, 2002; Bluck et al., 2005). All these processes are disturbed in MDD and therefore dysfunction of AM could be one of the main dysfunctions in depression (Dalgleish & Werner-Seidler, 2014). Disturbed AM processing in MDD is mainly characterized by a negativity bias and overgeneral recall (Hitchcock et al., 2017; Liu et al., 2013). Both aspects are described below.

There is a negativity bias in MDD towards emotionally valenced information. For example, people with depression can retrieve mood-congruent, negative material more easily from the episodic or verbal memory (e.g., Mathews & MacLeod, 2005). In MDD negative memories are easier and faster to recall (for a review see (Gotlib & Joormann, 2010), whether they are cued or spontaneously remembered (e.g., Lemogne et al., 2006). Recalling positive AMs may be more difficult (Dalgleish & Werner-Seidler, 2014) and they do not enhance mood in depressed or dysphoric individuals as they do in healthy samples (Joormann et al., 2007; Joormann & Siemer, 2004). Because positive retrieval is highly effortful in people with MDD, positive memories may have lower reward value when recalled (review by Chen et al., 2015). It was also shown that positive AM recall in people with MDD may even worsen current negative mood.

Regardless of emotions, autobiographical memories may be either specific or general. Specific AMs refer to events that happened at a particular time and place and lasted up to one day (e.g., “my wedding day”). General AMs refer to events that were repeated or lasted longer than one day (e.g., “yearly holidays in France”; (A. C. Holland & Kensinger, 2013; Köhler et al., 2015; Sumner et al., 2010; Williams et al., 2007). Among different psychiatric disorders, including depression, there is a reported tendency to recall fewer specific events and more general ones. This effect was termed *overgeneral memory* (see Williams et al., 2007 for a review of memory specificity in affective disorders). One of the possible explanations for why this effect is present in depression is that it may be influenced by limited cognitive resources in MDD, such as difficulties with working memory (Çili & Stopa, 2019, Chapter 4).

Despite the importance of AM in the outcome and course of depression, relatively little is known about AM’s neural basis in this disorder. It may be expected that in MDD the core regions processing AM (such as the hippocampus) may be functioning abnormally due to their differential activation during different cognitive tasks or significant volume loss observable in this disorder (Schmaal et al., 2016). Up to date only several studies examined the AM recall in

depression using fMRI. These studies compared positive and negative memories which were prompted by positive and negative words (Young, Bodurka, et al., 2016; Young et al., 2012, 2013, 2014; Young, Siegle, et al., 2016). All the studies used non-memory control tasks. Below, I will describe the results derived from comparisons between currently depressed and healthy control groups.

On the behavioral level it was found that depressed participants recalled fewer specific, positive, and arousing AMs than the control groups (Young et al., 2012, 2013). The neuroimaging results were mostly inconsistent across the studies. In the study by Young and colleagues (2012) the AM recall was compared to a control task, regardless of the memories' valence or specificity. Depressed individuals, compared to the control group, showed decreased activation of the dlPFC, ACC, anterior and posterior insulae, hippocampus, parahippocampal gyrus, MTG, TPJ, inferior occipital gyrus, and cuneus. The authors suggested that the diminished hippocampal/parahippocampal activation was associated with volume loss within these regions that is common in depression (e.g., Sheline et al., 2003). Moreover, they suggested that these functional differences may have reflected differences in the levels of vividness of AMs, as both regions have been implicated in retrieval of memory details. However, vividness was not measured in this study. Results concerning the ACC were also discussed. The authors found that greater activation of ACC was related to greater subjective ratings of emotional arousal, however, this relationship was stronger in the control group. Because ACC is thought to be engaged in processing of autonomic arousal (Critchley et al., 2003) and emotional states (Allman et al., 2001), and because the MDD group recalled fewer arousing AMs, the authors suggested that depressed participants experienced less autonomic and emotional reactivity during the task.

Two other studies distinguished between general and specific AMs (Young et al., 2013, 2014). When specific AMs, regardless of their valence, were compared to the control task, the MDD group (vs the control group) had higher activation of the middle frontal gyrus (MFG), frontal operculum, ACC, cuneus (Young et al., 2013), dmPFC, anterior insula, hippocampus, and parahippocampal gyrus (Young et al., 2014). It was suggested that elevated engagement of these regions reflected greater processing of self-referential and emotional information during AM recall, and that the MDD individuals possibly engaged in ruminative negative thinking (Young et al., 2013). Moreover, greater activation of the dmPFC suggested that the MDD group faced greater difficulties when completing the recall task, as this region was previously found to be engaged in executive control and its activity was found to reflect the difficulty of a task (e.g., Kalbfleisch et al., 2007).

Other studies distinguished between positive and negative AMs (Young, Bodurka, et al., 2016; Young et al., 2014; Young, Siegle, et al., 2016). An overview of the results from these studies is presented at Figure 3. When the groups were compared for the positive AM recall (vs the control tasks) the MDD group showed lower activation of the precuneus, PCC (Young et al., 2014), anterior insula, vlPFC (Young, Bodurka, et al., 2016), and amygdala (Young, Bodurka, et al., 2016; Young, Siegle, et al., 2016), and higher activation of the parahippocampal gyrus (Young, Bodurka, et al., 2016; Young et al., 2014), hippocampus, dmPFC (Young et al., 2014), MFG, and PCC (Young, Bodurka, et al., 2016). Higher activation of the hippocampus, PCC, dmPFC and MFG could reflect greater effort put into recall (Addis et al., 2004; Young, Bodurka, et al., 2016). Moreover, lower activation of the amygdala, insula and vlPFC suggests that positive AMs are less important to the self, less emotionally arousing, and that they do not up-regulate the current mood (Young, Bodurka, et al., 2016). It was suggested that less salient AMs may be less frequently retrieved. Perhaps in turn this causes less detailed recall (Young, Siegle, et al., 2016).

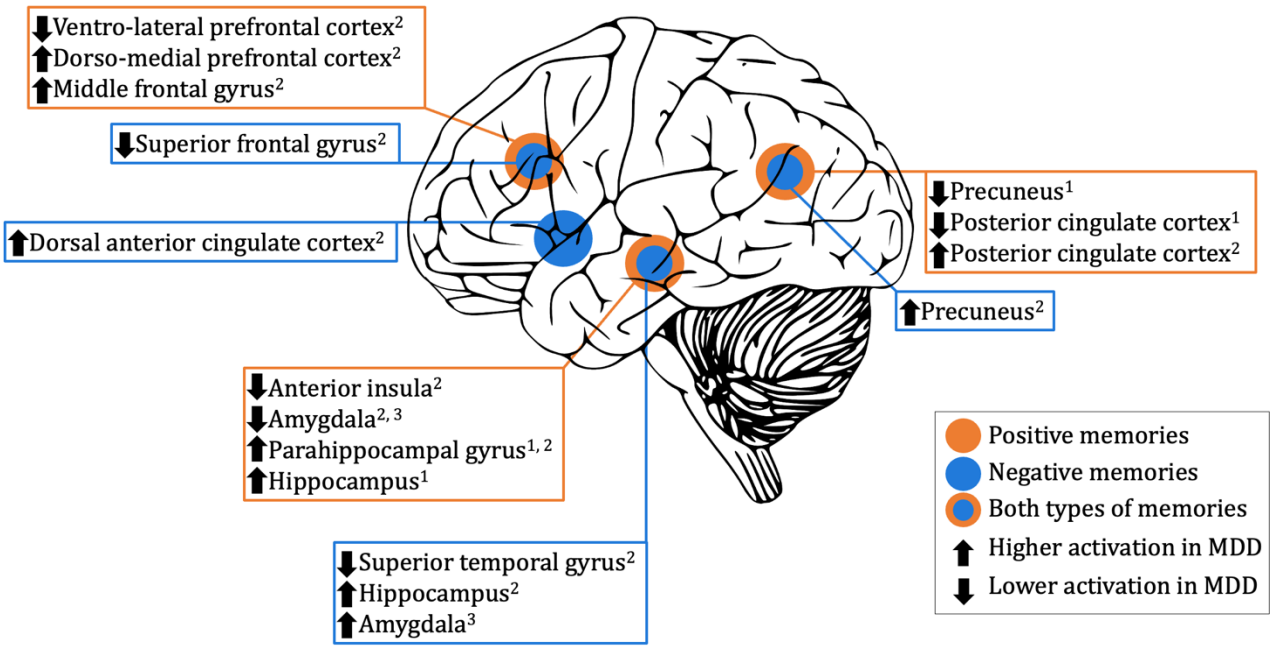


Figure 3. An overview of the brain regions previously found to be implicated in recall of positive and negative autobiographical memories in MDD. [1]Young et al., 2014; [2]Young, Bodurka et al., 2016; [3]Young, Siegle et al., 2016.

During negative AM recall (vs the control tasks) depressed individuals had lower activation of the superior temporal gyrus (STG; Young et al., 2014), and superior frontal gyrus (Young, Bodurka, et al., 2016) and higher activation of the dorsal ACC, precuneus, amygdala

(Young, Bodurka, et al., 2016), and hippocampus (Young et al., 2014). A recurrent result was greater amygdala engagement in the negative AM recall. Young, Siegle et al. (2016) compared negative to positive AMs and found increased activity in the left amygdala for the MDD group (vs the control group). Greater involvement of this region suggests greater emotional arousal during negative recall.

Only one of the above-mentioned studies also examined functional connectivity. It showed that for positive AMs MDD group had decreased amygdala connectivity with dorsal ACC and PCC, and increased amygdala connectivity with mPFC and STG (Young, Siegle, et al., 2016). For the negative AMs MDD group had increased amygdala connectivity with dorsal ACC, STG, insula, dlPFC, PCC, thalamus, MTG, precuneus, inferior temporal gyrus and amygdala itself. According to the authors, decreased coactivation between amygdala and other regions during positive retrieval supports abnormal processing of positive information and could provide a marker for depression. It also shows that positive AMs are not salient or relevant to the self for people with MDD, therefore these memories may be retrieved less effortfully. On the other hand, increased amygdala connectivity for negative AMs suggests their salience and importance, and easier recall.

These results show differential, possibly abnormal functioning of the core regions processing autobiographical memory in depression. Nevertheless, the literature on this topic is still scarce and more studies are needed to explain the mechanisms and basis of the AM disturbances in MDD.

1.2.7. Autobiographical memory in borderline personality disorder

People diagnosed with BPD experience disturbed sense of identity, have mostly negative self-image, and have difficulties with self-regulation. They have difficulties with understanding their past experiences, imagining future events and, therefore, with establishing goals (Bech et al., 2015). These disturbances may be influenced by autobiographical memory, which was suggested to be overgeneral in BPD (Maurex et al., 2010). One study showed that overgenerality was present in people with BPD, however, regardless of a co-occurring depressive episode or PTSD (Maurex et al., 2010). On the other hand, other studies found no evidence for overgeneral memory in BPD (e.g., Renneberg et al., 2005). Individuals diagnosed with BPD may also recall more negative than positive AMs and are more likely to retrieve AMs about BPD-related themes: rejection, abandonment, and negative evaluation (Bech et al., 2015; Jørgensen et al.,

2012; Rosenbach & Renneberg, 2015). What is more, the memories of social rejection may also be more focused on the self, may be recognized as more relevant to the present self, and are related to feelings of anger (Rosenbach & Renneberg, 2015).

Up to date, the neural underpinnings of the AM in BPD were a subject of scarce interest among researchers. Only a few studies examined the autobiographical recall in BPD with the use of fMRI. Two of those studies compared negative unresolved and resolved AMs (Beblo et al., 2006; Bozzatello et al., 2019). An overview of the results from these studies is presented in Figure 4. The *unresolved* memories may be perceived as more important to the self, influencing the present life, difficult to cope with, and they evoke strong emotional reactions. The *resolved* memories are perceived as overcome, concluded, integrated into the self, and they do not elicit intense emotions during recall (Beblo et al., 2006; Beike & Wirth-Beaumont, 2005; Öner & Gülgöz, 2018; Skowronski et al., 2014). Beblo et al. (2006) compared a group of women with BPD (undergoing dialectical behavioral therapy) to a healthy control group. The BPD group rated the unresolved AMs as related to higher levels of anxiety, helplessness, and feelings of derealization. On the neural level, within this group, the unresolved AMs had higher activation of the insula, amygdala, ACC, PCC, and occipital cortex, than the resolved memories. Group comparison showed that the BPD individuals had higher activity in the frontal operculum, insula, amygdala, OFC, occipital cortex, and cuneus for the unresolved AMs than the control group. The authors suggested that higher engagement of the amygdala and insula in the BPD group was related to stronger emotional experiences during unresolved recall, and especially to feelings of anxiety as shown by the behavioral results. Moreover, higher activation of the ACC and orbitofrontal cortex was suggested to reflect greater effort to control the amygdala-mediated emotional responses. It was also suggested that additional activations of the PCC and occipital cortex indicated greater visualization of the unresolved memories in the clinical group.

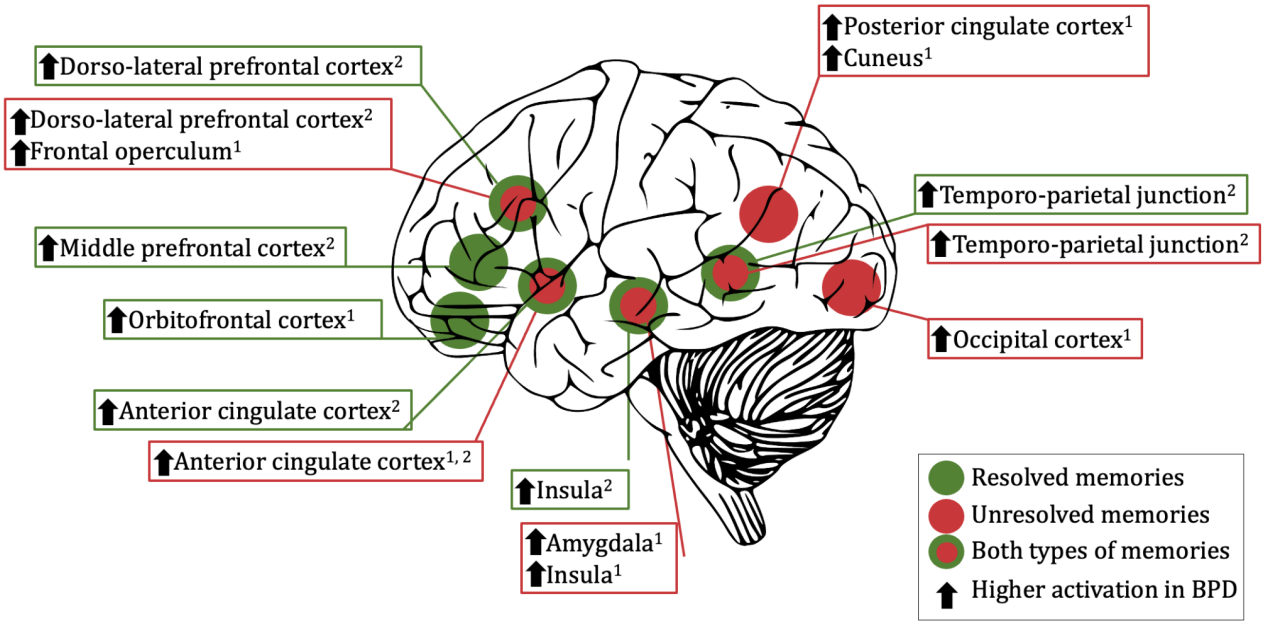


Figure 4. An overview of the brain regions previously identified as implicated in the recall of resolved and unresolved autobiographical memories in BPD. [1]Beblo et al., 2006; [2]Bozzatello et al., 2019.

The study by Bozzatello et al. (2019) showed different results. Within the BPD group, the resolved AMs showed higher activation of the TPJ and insula, in comparison to neutral memories. When the BPD group was compared to the healthy controls, it had increased activation for the resolved memories in the mPFC, anterior insula, dlPFC, and ACC than for the neutral AMs. As for the unresolved AMs, compared to the neutral ones, the BPD group had higher activation of the ACC, dlPFC, and TPJ, than the control group. The authors pointed out that the ACC and dlPFC were more engaged in the clinical group, regardless of the condition. These regions were previously linked to integration of attentional and emotional information (e.g., Bush et al., 2000), control of the AM retrieval (Cabeza & St Jacques, 2007), and creation of coherent life narratives (e.g., Lemogne et al., 2010). Based on those findings it was suggested that the BPD group experienced the AMs as poorly integrated narratives, or as overgeneral memories. The authors also discussed higher engagement of the insula during resolved AMs recall. They suggested that these memories were excessively emotionally processed during the task, and that they may not be fully "resolved" and integrated with the self within the BPD individuals.

Unfortunately, no neuroimaging studies examined functional connectivity during AM retrieval in BPD.

In conclusion, it seems that the topic of AM recall received even less attention in the BPD than in the MDD population. Due to a small number of studies, different paradigms, and rather small samples the knowledge about AM in BPD is very limited, and more studies are needed.

1.2.8. Similarities and differences between major depressive disorder and borderline personality disorder in autobiographical memory

To my knowledge, there are no brain imaging studies comparing MDD and BPD in processing AM. Both disorders were only compared on the behavioral level. The results vary between the studies. For example, Arntz and colleagues (2002) showed that the BPD group did not present overgeneral AM, while the MDD group did. Another study showed that the groups did not differ based on retrieval of specific memories, but the MDD group retrieved more general AMs (Renneberg et al., 2005). On the contrary, Rosenbach and Renneberg (2015) did not show differences between MDD and BPD groups for overgeneral recall. Moreover, one study showed that both clinical populations recalled more negative AMs than the healthy population (Renneberg et al., 2005).

Available literature that focused separately on either MDD or BPD during AM recall does not provide analogical results or conclusions due to gross differences in study designs. Studies examining MDD groups focused on general vs specific or negative vs positive AM recall, while studies with BPD groups mainly focused on resolved vs unresolved memories. Nevertheless, some preliminary similarities between the groups can be observed. In response to negative memories and to resolved/unresolved negative memories, MDD and BPD groups had higher activation of the ACC (Bozzatello et al., 2019; Young, Bodurka, et al., 2016), amygdala (Beblo et al., 2006; Young, Bodurka, et al., 2016; Young et al., 2014), hippocampus (Young, Bodurka, et al., 2016; Young et al., 2014), precuneus, and cuneus (Beblo et al., 2006; Young, Bodurka, et al., 2016). It is possible that both disorders present similar alterations during AM recall, regarding emotional processing and retrieval. However, future work directly comparing the disorders during AM recall is needed in order to uncover similarities and differences between them and broaden our understanding in this area.

1.3. Emotion regulation

1.3.1. Emotions and emotion generation

Emotions were always of great interest for philosophers and scientists alike. They play a role in our social lives, facilitate learning, or maintain goal-directed behavior. Emotions are a major research area that have been growing for decades. However, there is still little consensus about the nature and definition of emotion, which is reflected by multiple theories and approaches. For example, Ekman proposed a *theory of basic emotions* which suggested that affective experience draws from a set of distinct biologically basic emotions (sadness, happiness, fear, anger, surprise, disgust). He argued that these emotions are evolutionarily adaptive, and have universal behavioral and physiological correlates (Ekman, 1999). In line with this theory emotions may be generated through quick *bottom-up* processes. They elicit emotions through the perception of simple and inherently emotional stimuli, for example seeing a snake under one's feet. In laboratory settings such stimuli could be emotional pictures (McRae et al., 2012).

As the theory of basic emotions has some limitations other approaches were developed over the years. More significant to the present thesis are *appraisal theories*. For example, according to the *modal model* emotions emerge from a relationship between a person and a psychologically relevant situation. A person perceives and attends to a stimulus, then appraises it and gives it meaning or significance. This in turn triggers affective, behavioral, and physiological reactions (Barrett et al., 2007). Similarly, the *circumplex model of affect* assumes that emotions derive from a combination of two dimensions - *valence* (psychological experience of pleasantness or unpleasantness) and *arousal* (neurophysiological alertness; Posner et al., 2005). In accordance with appraisal theories emotions should be generated by *top-down* processes, driven by cognition and specifically, by elaboration of a stimulus. In laboratory settings top-down emotion generation could be elicited by, for example, autobiographical scripts or narratives inducing appraisals (McRae et al., 2012).

One more approach based on appraisal theories of emotions, which is also a basis for understanding emotion regulation, is *the valuation perspective* (term "valuation" is interchangeable with "appraisal" or "evaluation"; Gross, 1998; Ochsner & Gross, 2014). It assumes that emotional responses arise from valuations of stimuli. The process starts with *a world-perception-valuation-action cycle* (W-PVA; Ochsner & Gross, 2014). The external or internal world provides stimuli and information (e.g., somebody's behavior, one's thoughts) for the perception stage, in which different sensory systems are engaged. Then, in the valuation

stage, these stimuli are appraised (e.g., a room full of people can be valued as stressful or as entertaining), and in the action stage behavioral, emotional, mental, and physiological responses appear (e.g., stepping out of a party, sweating, increased heart rate, retrieving a memory of a similar situation).

Valuations can be divided into 3 categories, and each may be related to activity in different brain regions (Ochsner & Gross, 2014). *Core valuations* represent direct and usually unconscious associations between a stimulus and a reaction (e.g., snake elicits fear response). They may rely on activity within the ventral striatum and amygdala, which are related to appraisals of valence or aversiveness of stimuli (e.g., Holland & Gallagher, 2004). *Contextual valuations* represent appraisals of stimuli in certain contexts - social, motivational, historical (based on past experiences). These may rely on activity within the orbitofrontal cortex, vmPFC, MTL (which provide spatial and temporal context, e.g., Murray et al., 2007), superior temporal sulcus and TPJ (which reorient attention based on expectation about others' actions and intentions, e.g., Saxe, 2006), and anterior insula (which is related to body state awareness, e.g., Zaki et al., 2012). The third type of valuations is *conceptual*. These appraisals are abstract, aware, and possible to verbalize. They could be related to activity within the rostromedial PFC, dmPFC, vlPFC (which are engaged in attention, judgement of the value of stimuli, categorization, e.g., Lindquist et al., 2012), and anterior insula.

Even though multiple neuroimaging methods allow us to study emotions on a detailed biological level almost in real time, due to multiplicity of theories and models of emotions, there is no final consensus in the literature as to how brain's mechanisms relate to generation (and regulation) of emotions. Even meta-analysis studies are unable to point towards unique processes for specific emotions (Clark-Polner et al., 2016). However, some brain regions are consistently reported in studies of emotions, for example the amygdala, insula, dmPFC, and vmPFC (Silvers & Guassi Moreira, 2019). The amygdala is implicated in generating emotional responses (LeDoux, 2000) and its activity may indicate intensity or salience of stimuli (Cunningham & Brosch, 2012). The insula is activated together with the amygdala in response to negative and salient stimuli, and it motivates behavior (meta-analysis by Lindquist et al., 2016). The mPFC is associated with top-down emotion generation and regulation (e.g., Ochsner et al., 2009). The dmPFC is involved in generating fear responses and negative emotions (e.g., Ochsner et al., 2009), and in social cognition (meta-analysis by Denny et al., 2012). The vmPFC is involved in updating the affective significance of stimuli based on contextual and memory inputs (e.g., Delgado et al., 2016). Even though these brain regions are reported in studies of emotions, they are not specific to emotionality but are related to other processes as well. Also,

perhaps specific brain activity patterns or activity of networks should be looked at rather than activation within brain regions separately (Clark-Polner et al., 2016).

1.3.2. Emotion regulation

Together with emotion generation comes *emotion regulation* (ER). This process helps understanding emotional responses to thoughts and situations, to decide which emotions are experienced, when they are present, and how they are expressed (Gross, 1998). Both positive and negative emotions can be down- or up-regulated: decreased or increased, respectively, in intensity and duration. ER has an impact on our well-being, psychological and physical health, and interpersonal functioning (Clark-Polner et al., 2016).

The valuation perspective described above (W-PVA) is also suitable for describing emotion regulation. In its light ER is a valuation process targeting a valuation that generates emotions (Suri & Gross, 2016). If a goal of changing an emotional reaction emerges, ER process begins. Different regulatory strategies can be used at consecutive stages of W-PVA cycle, such as cognitive reappraisal at valuation stage, while other strategies may not fit into this model, such as mindfulness (Suri & Gross, 2016; although Farb et al., 2014 suggested that it fits into the perception stage). Both ER strategies are described in the further sections.

The topic of emotion regulation has been broadly studied in the neuroimaging field. Although the results mostly depend on regulation strategies, it seems that in general, during ER the prefrontal regions (such as vlPFC, dlPFC, and dorsal ACC), which are typically involved in cognitive and attentional control processes (Mitchell, 2011) influence the subcortical regions (such as the amygdala) that are processing and generating emotions (Johnstone & Walter, 2014).

Further description of the neural basis of ER is presented in sections regarding cognitive reappraisal and mindful acceptance.

1.3.3. The strategy of cognitive reappraisal and its neural underpinnings

Cognitive reappraisal (CR) is one of the adaptive ER strategies, which up to date has been extensively studied. It relies on changing the meaning of a situation in order to change an emotional response to that situation (Gross, 2002). Reappraisal technique called *distancing* means that we distance ourselves psychologically from an emotional stimulus (e.g., while crying

during a sad scene in a movie we can remind ourselves that it's just a movie and nothing more). A technique called *reinterpretation* is based on thinking about alternative appraisals that disagree with the preliminary interpretation of a stimulus and change its meaning (e.g., a failed job interview can be reinterpreted as a chance to improve one's skills). Cognitive reappraisal can be used to either down-regulate negative emotions or up-regulate positive ones. However, the literature most often shows it as a down-regulatory strategy and this form, together with reinterpretation technique, is of interest for the present dissertation.

Current literature shows that CR is successful in decreasing negative emotions and expressions caused by these emotions (Gross, 1998). The more it is practiced the more effective it is in diminishing negative emotions (Denny & Ochsner, 2014).

Up to date multiple neuroimaging studies on CR have been conducted. CR could have similar neural underpinnings as emotion generation process. Clark-Polner et al. (2016) compared meta-analytic findings by Buhle et al. (Buhle et al., 2014) to meta-analyses of neuroimaging studies of emotion generation. They pointed out that the areas of overlapping activation were the vlPFC, anterior insula, ACC, supplementary motor cortex, posterior superior temporal sulcus. This suggested that ER and emotional experience share similar mechanisms. However, other results showed differences. For example, CR was related to posterior middle frontal gyrus and intraparietal lobe, which are engaged in selection of stimuli important for goal-directed behavior, while emotion generation was related to activity in mPFC and PCC - parts of the default mode network. However, Clark-Polner and colleagues (2016) expressed that the differences in brain activations may arise from differences in task paradigms, in how the emotions were elicited, and which aspects of CR were used as a strategy by participants.

Reappraisal is a process that seems to engage multiple other processes: cognitive control, working memory, language processing, attention, monitoring (Goldin et al., 2019). According to Ochsner and Gross (2008), reappraisal should involve interactions between regions responsible for cognitive control processes and regions processing and monitoring emotions (also Ochsner & Gross, 2014). Indeed, single and meta-analytic studies have shown that reappraisal recruits prefrontal and parietal regions (such as dlPFC, vlPFC, dmPFC, dorsal ACC), and that it increases or decreases activity (depending on up- or down-regulation, respectively) in, for example, the amygdala and insula (meta-analysis by Buhle et al., 2014; review by Silvers & Guassi Moreira, 2019; also Ochsner & Gross, 2008; Wager et al., 2008; Figure 5).

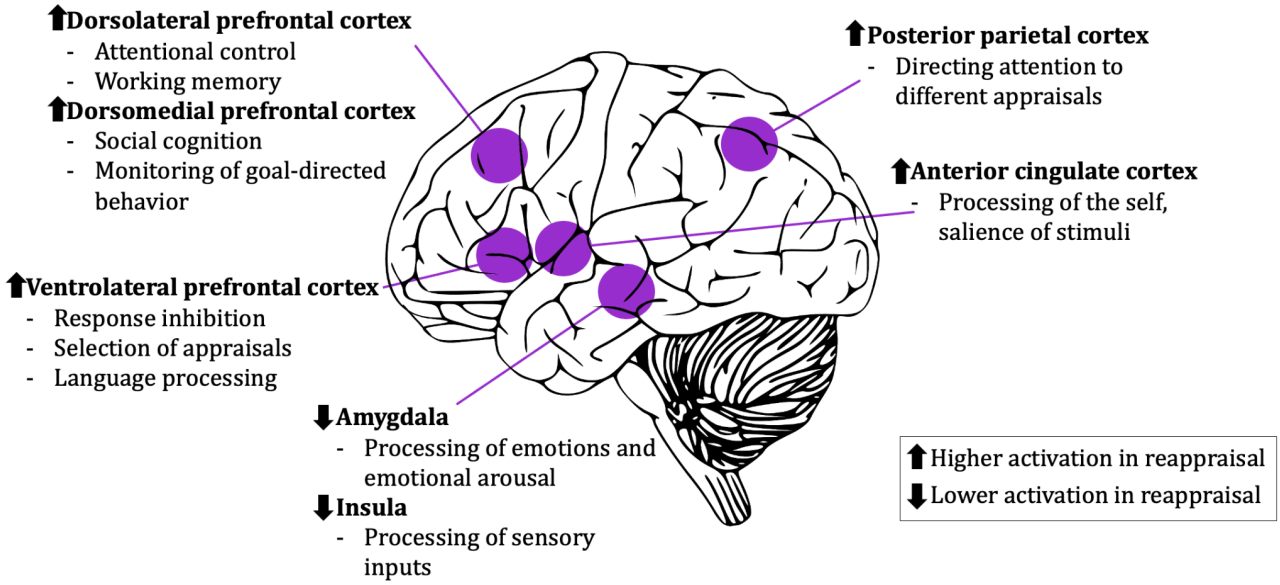


Figure 5. An overview of the main brain regions implicated in cognitive reappraisal. Based on the results of the meta-analysis by Buhle et al., 2014.

The dlPFC region, among other functions, controls attention and working memory (meta-analyses: Cieslik et al., 2015; Rottschy et al., 2012). During reappraisal, dlPFC together with the posterior parietal cortex could direct attention to different appraisals and select them from working memory (Buhle et al., 2014). Posterior parietal cortex may also process how important are the emotional stimuli (Ochsner et al., 2004, 2012). The vlPFC is involved in response inhibition, selection of appraisals (Cieslik et al., 2015; Ochsner et al., 2012), and in language processing (Ochsner et al., 2012). The dmPFC is involved in social cognition and monitoring goal-directed behavior (meta-analyses: Denny et al., 2012; Northoff et al., 2006). According to Silvers and Guassi Moreira (2019), during reappraisal dmPFC could appraise affective states and personal goal of regulation. The dorsal ACC monitors control processes and their effectiveness (Buhle et al., 2014; Ochsner & Gross, 2008). Reappraisal also engages other regions, such as the supplementary motor area, which is involved in cognitive control, precuneus, which is engaged by attentional processes, or middle temporal gyrus and angular/supramarginal gyrus, which process language (Buhle et al., 2014; Ochsner et al., 2012).

Activation of the prefrontal regions should influence the limbic regions and diminish their activation in order to down-regulate negative emotions (Ochsner & Gross, 2008). The main region that seems to be regulated during reappraisal is the amygdala, which is engaged in detecting and encoding emotional stimuli, and processing emotional arousal (Buhle et al., 2014; Goldin et al., 2008; Phelps, 2006). Other regions modulated by reappraisal are the ventral

striatum, insula, and vmPFC - with the two latter being the least commonly reported in the literature (Ochsner et al., 2012). The meta-analysis by Buhle et al. (2014) did not show vmPFC recruitment during reappraisal at all.

Several studies to date examined functional connectivity during cognitive reappraisal (using down-regulation) in healthy adults. Their results are inconsistent, possibly due to different methodologies (task designs, analysis methods). For example, in a study by Sarkheil and colleagues (2019), during CR of negatively valenced pictures there was a negative correlation of activation between the amygdala and left PFC, and a positive correlation between the amygdala, insula, and ACC. Another study showed that during down-regulation of negative emotions there was positive connectivity between the IFG and dlPFC, dmPFC, and vlPFC, but not with amygdala (Morawetz et al., 2017). One more example can be an older study, by Banks and colleagues (2007), in which during CR positive functional connectivity was observed between the left amygdala and dlPFC, OFC, dmPFC, ACC, and inferior parietal lobe.

Because of inconsistencies in the literature, Berboth and Morawetz (2021) decided to perform a meta-analysis of emotion regulation studies, which used psycho-physiological interactions analysis to test for functional connectivity between amygdala and other brain regions. Most of the studies used CR strategy and negatively-valenced stimuli. Authors performed an analysis in which ER strategies, regulation goals (down- or up-regulation), or stimulus valence were taken together, and an analysis in which they looked at impact of CR, down-regulation, and negatively valenced stimuli. The first analysis showed that independently of strategy, goal, and valence there was a positive connectivity between the amygdala and the left vlPFC. The second analysis revealed positive connectivity between the amygdala and the right dlPFC, left vlPFC, and right dmPFC. As the vlPFC was present in both results, the authors concluded that (a) it might be a key region integrating emotion generation and regulation, especially during CR, and (b) it could support reinterpretation of stimulus' meaning as vlPFC is involved in language processing. Similar result was obtained in a meta-analysis by Di et al. (2017). Regarding connectivity of dlPFC and dmPFC with the amygdala during CR authors suggested that the dlPFC could engage greater cognitive control during CR, while dmPFC could guide attention towards mental states of people presented on visual stimuli (Berboth & Morawetz, 2021).

Studies using self-report as well as neuroimaging methods showed that cognitive reappraisal is an effective and adaptive emotion regulation strategy which diminishes subjective negative emotional experience and improves well-being. However, despite numerous studies on CR, its neural mechanism is not yet fully understood. Because reappraisal

is a part of therapeutic interventions, such as the cognitive-behavioral therapy, better knowledge of its processes could improve therapeutic techniques and models.

1.3.4. The strategy of mindful acceptance and its neural underpinnings

For the past years mindfulness gained recognition in the scientific community and has been extensively studied. It is a technique or a concept that emerged from Buddhism. In the literature mindfulness is defined very differently and studied with various methods - mindfulness, mindful acceptance, relaxation, meditation (e.g., loving-kindness meditation), mindful breathing, mindful attention, etc. Due to this heterogeneity, it can be difficult to choose research to rely on. In my dissertation I focused on the term *mindful acceptance* (MA) and task instructions that come with this term (e.g., Kober et al., 2019).

MA aims to support well-being, relies on attending to emotions and on guiding attention to the present moment, promotes openness and acceptance of one's thoughts and feelings (regardless of their nature), and helps in reducing automatic responses and valuations (Bishop et al., 2004; Farb et al., 2014). Instead of guiding attention to a stimulus and to possible different interpretations as in CR, MA teaches people to guide attention away from the stimulus and evaluations, and towards the internal states, sensations from the body, breath, and heartbeat (Farb et al., 2007, 2013; A. Lutz et al., 2009).

Studies on MA showed that it is an adaptive regulatory strategy, especially for anxiety and mood disorders such as depression (Hofmann et al., 2010) as it, for example, reduces ruminative thinking (Feldman et al., 2010) or diminishes reactive, non-adaptive appraisals and replaces them with interoceptive attention (Farb et al., 2014). Its practice has been included in various psychotherapeutic interventions, such as the dialectical-behavioral therapy, mindfulness-based stress reduction, or mindfulness-based cognitive therapy. The success of mindfulness in enhancing mental well-being shows how important it is to understand its neural processes.

Available frameworks proposed neurocognitive processes that could underlie mindfulness: attentional and cognitive control (especially attention regulation, inhibition, and switching), emotion regulation, and self-related processing. Together with motivation these processes may enable mindfulness to change one's behavior (Hölzel et al., 2011; Schuman-Olivier et al., 2020).

Neural mechanisms of MA may differ depending on the person's experience in using it (see review by Schuman-Olivier et al., 2020; Figure 6) but even with mindfulness-naive participants the literature shows different results. Lutz et al. (2013) showed a decreased activation in the right amygdala, right hippocampus, and left insula and increased activation in the left middle frontal gyrus when participants were engaging in MA while looking at negative pictures, compared to participants who were not engaged in any ER strategy. Such result suggests a regulatory function on the limbic system and enhanced cognitive processing within the frontal cortex. Another study showed that healthy participants had higher activation of bilateral frontal poles, right ACC, left orbitofrontal cortex, and right precentral gyrus when they were using MA while looking at sad pictures, as compared to just looking (Smoski et al., 2015). In the study by Goldin et al. (2019) participants provided descriptions of social situations from their own experience and negative self-beliefs corresponding to these situations. During the task participants were asked to (a) read neutral statements, (b) react to negative self-beliefs by considering how true they were, (c) use CR to reframe the beliefs, or (d) use mindful acceptance. MA, compared to reacting, resulted in higher activity in the bilateral superior frontal gyri and inferior frontal gyri, left middle temporal gyrus, bilateral angular gyri, bilateral inferior parietal gyri, left precuneus, bilateral caudate, and less activity in the left acc and left supramarginal gyrus. No differences were found between MA and reacting for the amygdala. These findings suggest that MA engages significantly more cognitive control, however it did not down-regulate amygdala's activity.

A recent meta-analysis (Messina et al., 2021) included 13 fMRI studies in total that used mindful acceptance as a regulation strategy. Comparison of acceptance to all control conditions did not yield significant results, which was in accordance with other literature showing no significantly increased activation during acceptance (e.g., Kober et al., 2019). However, there was a significant difference in favor of control conditions showing increased activation in a cluster containing thalamus, PCC, lingual gyrus, parahippocampal gyrus, posterior insula, and cuneus. Further analysis comparing acceptance only to natural reactions to stimuli as control condition showed heightened activation during acceptance in the anterior insula, putamen, IFG, MFG, superior frontal gyrus, and ACC. In this comparison during natural reactions higher activation was found in the PCC/precuneus, hippocampus, and STG. According to the authors, the significant differences between acceptance and natural reaction to emotional stimuli could derive from a difference in cognitive effort but not necessarily from a regulatory effect.

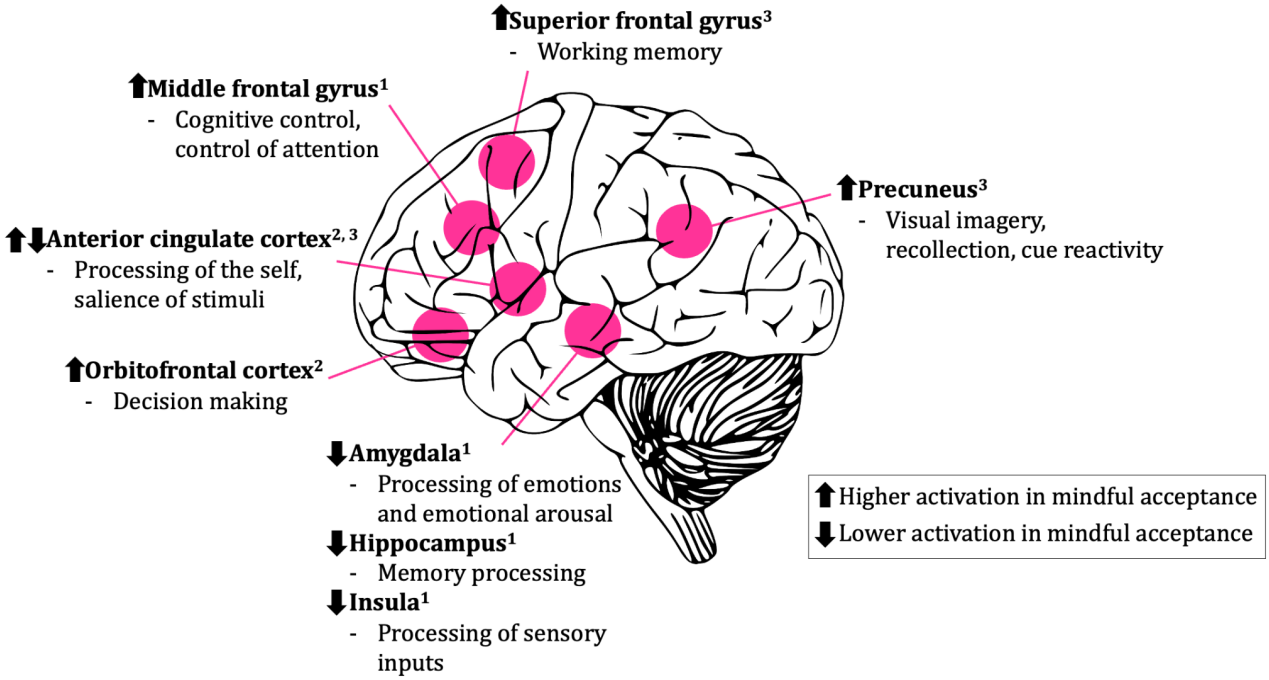


Figure 6. Some of the brain regions previously found to be engaged in mindful acceptance. [1]Lutz et al., 2013; [2]Smoski et al., 2015, [3]Goldin et al., 2019.

When it comes to fMRI functional connectivity literature, the available studies use different task instructions than MA, analyze resting state rather than task-based connectivity, and mostly regard outcomes of mindfulness-based interventions with participants who already have a level of experience with mindfulness techniques. Therefore, no previous functional connectivity studies are discussed.

Despite growing interest in mindfulness and meditation, and their impact on human mental well-being, our understanding of MA as an ER strategy is still very limited.

1.3.5. Brief comparison of cognitive reappraisal and mindful acceptance

Cognitive reappraisal is based on voluntary reinterpretation of emotional stimulus, while mindful acceptance focuses attention on experiencing thoughts and emotions without trying to change them. Even though these are two distinct strategies, they could share some of the attentional processes (Goldin et al., 2019), however, only a few studies directly compared these strategies.

When it comes to the efficacy in reducing sadness studies' results are not consistent - some show no differences between CR and MA (Goldin et al., 2021; Keng et al., 2013; Wolgast

et al., 2011), while others showed greater effectiveness of CR (Goldin et al., 2019; Smoski et al., 2015; Troy et al., 2018). Moreover, two of these studies compared ratings of subjective success of following instructions. The study by Troy et al. (2018) showed that participants rated MA's instructions as easier to follow and that it was a more successful strategy than CR, even though it did not significantly lower negative emotions. Another study did not show any differences in perceived success between the strategies (Wolgast et al., 2011).

There are some studies that compared neural mechanisms of CR and MA. In a study by Smoski et al. (2015) healthy participants had higher activation during CR than MA of the PFC regions: frontal pole, MFG, IFG, and left frontal operculum. On the other hand, MA resulted with higher activation of the left insula and left precentral gyrus. The authors suggested that insular activity reflected task instructions to be aware of one's emotions. Also, as insular activity was positively correlated with higher intensity of negative affect, MA could have been less effective in regulation due to possible heightened emotional awareness.

Goldin and colleagues (2019; methodology described in the above chapter) showed in general no significantly higher activations during MA than CR. However, when CR was compared to MA, it resulted in higher activity in left dorsal ACC, left MFG, left precentral gyrus, bilateral middle temporal gyri, left inferior parietal lobule, bilateral lingual gyri, bilateral fusiform gyri, bilateral middle occipital gyri, and right caudate. The amygdala showed bilaterally lower activity than during MA. The authors suggested that lack of greater brain activity for MA than for CR could mean lesser cognitive control engagement.

1.3.6. Selected aspects of research paradigms in emotion regulation studies

Emotion regulation may be studied with the use of self-report measures or with experimental methods (Aldao et al., 2010). In self-report studies the participants fill out questionnaires and diaries that measure different aspects of ER or rate, for example, how often they use certain ER strategies in daily life. These studies may assess long-term patterns of emotional responding and usage of regulatory strategies in vivo. The use of those methods is less time and money consuming, and they allow for studying larger groups of people. However, they may be confounded with self-presentation biases (Aldao et al., 2010).

In experimental studies participants are often instructed to use a particular regulation strategy while attending to emotional stimuli (Aldao et al., 2010). The stimuli are usually negatively valenced pictures. During the procedure emotional responses could be measured

with self-report ratings of current emotions, or with physiological and neuroimaging techniques. Such studies do not rely fully on participants' self-beliefs and provide more objective results.

1.3.7. Emotion regulation in major depressive disorder

Difficulties with emotion regulation are an inherent part of multiple mental disorders, including depression and BPD. In MDD the mood is almost incessantly negative, and the ability to experience positive emotions is very diminished. People with depression have difficulty regulating their negative state, therefore it lasts longer than in healthy people. They also engage more in maladaptive ER strategies (e.g., rumination or suppression; Nolen-Hoeksema et al., 2008). Engagement in maladaptive strategies could be caused by inaccessibility of the adaptive ones (e.g., because adaptive strategies were not taught to a child by caregivers), by cognitive biases (such as negative interpretations, or mood-congruency effects) or by diminished cognitive control processes (Joormann & Siemer, 2004).

Neuroimaging studies in general show that during ER the same prefrontal regions, that contribute to successful ER in healthy populations, present diminished activation in people with MDD and could be the cause of dysregulation in this disorder (Johnstone & Walter, 2014). According to a review by Rive et al. (2013) during voluntary cognitive processes (i.e., when participants are instructed to use strategies) involved in ER people with depression have equal or diminished activation of prefrontal regions when compared to healthy participants. However, during automatic ER (i.e., when participants are not instructed but report which strategies they used) and control processes people with MDD engage more strongly parietal cortex and lateral, dorsolateral, and ventrolateral prefrontal cortices than healthy people. This could be caused by hyperactivity of the limbic regions and by more cognitive effort needed. The authors suggest that in MDD successful ER is possible but perhaps only during early stages of the process, as compared to voluntary regulation when the emotional arousal is already at play. Nevertheless, the literature is still inconsistent.

The literature is also very limited when it comes to experimental studies involving participants with ongoing MDD and with reinterpretation as an ER strategy. Studies that involved patients with remitted depression and adolescents, used task instructions for distancing, or did not define which strategy was used in the task were of no interest to the present dissertation and therefore not discussed. Johnstone and colleagues (2007) compared

CR to looking at negative pictures and showed that group with MDD had greater recruitment of the right lateral PFC than HC. Also, in the MDD group greater activation of vmPFC was associated with greater activation of the amygdala. Therefore, the authors suggested that there was no amygdala regulation executed by the PFC in depression. Another study showed different results. During reappraisal people with MDD had higher activity within the left parahippocampal gyrus and left dmPFC than HC (Sheline et al., 2009). A recent study by Keller et al. (2022) also compared CR to looking at negative pictures between MDD and HC groups (and PTSD, not discussed). Within the MDD group CR engaged higher activity in the left IFG, left MFG, right cerebellum, left superior frontal gyrus, and left insula. When the groups were compared, healthy control had higher activation of the right precentral gyrus, right IFG, bilateral dmPFC, and supplementary motor cortex. A study by Fitzgerald and colleagues (2019) showed no significant differences between people with MDD, generalized anxiety disorder and social anxiety disorder neither in whole-brain analyses nor in functional connectivity. Heterogeneity of results from these studies shows how the literature is still very limited and does not provide sufficient evidence for neural processing of CR in MDD.

Literature on mechanisms of mindful acceptance in MDD is even more limited. Self-report studies, such as that by Didonna et al. (2019), show that people with MDD have lower levels of trait mindfulness than healthy people, and lower levels are related to more severe depressive symptoms and rumination. Smoski and colleagues (2015) used an instruction of mindful acceptance, however in a group of remitted patients. When they were compared to the control group, they had diminished activity of mPFC, dlPFC, MFG, and paracingulate gyrus during acceptance. The authors suggested that people with remitted MDD could still engage in ruminative thinking and have less cognitive control over their emotional states. Another study used an instruction of interoceptive awareness - participants were asked to observe internal states, thoughts, and feelings, however, without the element of acceptance (Herwig et al., 2018). The MDD group had lower amygdala activity in this task compared to neutral condition, which was interpreted as a successful down-regulation of this region.

This tremendous gap in knowledge proves how important it is to conduct more studies on the topic of ER in MDD, especially as more and more mindfulness-based interventions are being created.

1.3.8. Emotion regulation in borderline personality disorder

Severe difficulties with emotion regulation and high affective instability are core symptoms in BPD. People with this disorder have higher emotional sensitivity and reactivity to stimuli, and due to lack of regulatory resources they very slowly go back to affective baseline. They engage in maladaptive ER strategies, such as rumination, suppression, and avoidance, but also in auto-agressive and dysfunctional behaviors (e.g., self-harm, dissociation, substance abuse) in order to manage emotional responses (Daros & Williams, 2019; Reitz et al., 2012). The more severe symptoms of BPD, the more frequent use of maladaptive strategies and less frequent use of adaptive ones (Daros & Williams, 2019). Together with studies that showed diminished activation within the prefrontal cortex in response to emotional stimuli (e.g., Schulze et al., 2011), the literature suggests a dysfunction of prefrontal inhibitory processes and their impact on amygdala reactivity.

Some studies showed that people with BPD show no differences from healthy controls in reducing negative emotions while using CR, which could mean that they are able to use it effectively (meta-analysis by Daros & Williams, 2019), however they report themselves as less effective in using this strategy (Daros et al., 2020). To my knowledge the fMRI studies on CR in BPD used only distancing and none used reinterpretation. Therefore, only those studies will be discussed here, albeit very shortly.

Most of the studies used negative and neutral pictures as stimuli (Koenigsberg et al., 2009; Schulze et al., 2011; Silvers et al., 2016), and compared BPD groups to healthy controls (Lang et al., 2012; Koenigsberg et al., 2009; Schulze et al., 2011). Koenigsberg and colleagues (2009) showed that during distancing (as compared to looking at negative pictures) BPD participants had higher activation of the superior temporal sulcus, right superior frontal gyrus, and right amygdala than HC group. This result could suggest distancing to be less effective in regulating limbic activation, however other studies did not show similar amygdala reactivity. In fact, one more study showed lower engagement of amygdala during distancing in BPD patients, but there was no control comparison group (Silvers et al., 2016). Schulze et al. (2011) showed greater insular activation during distancing in BPD than in HC, while the control group had stronger engagement of various frontal regions (e.g., left IFG and MFG). Possibly the failure to engage frontal regions by BPD participants led to enhanced activation of the insular cortex, and the authors also suggested that it could be caused by prolonged emotional arousal due to clinical image of BPD. The link between ER and prefrontal activity was also shown in the study

by Silvers and colleagues (2016), where more difficulties with ER measured with self-report were related to lower activation of left IFG.

Studies show that trait mindfulness and acceptance are diminished in BPD populations, which in turn is related to more self-injuries. However, some studies showed that when patients are instructed to use mindfulness, they can be successful in it (meta-analysis by Daros & Williams, 2019). Among the fMRI neuroimaging literature only one study analyzed mindfulness in this population and used an instruction of self-focused introspection, i.e., noticing bodily sensations and thoughts, but without the acceptance aspect (Scherpiet et al., 2015). In comparison to the HC group, BPD participants during this condition had diminished activation of the amygdala, superior and middle frontal gyri, and increased activation of the motor cortex, IFG, and PCC. The authors suggested that these results showed down-regulation of the limbic structures and engagement in self-referential processing, however, participants were engaging in the instruction without any emotional stimuli present and did not have to regulate invoked emotional arousal. Therefore, it can be difficult to conclude if those results can underly neural mechanisms of mindfulness in BPD.

1.3.9. Similarities and differences between major depressive disorder and borderline personality disorder in emotion regulation

MDD and BPD are characterized by difficulties with emotion regulation and frequent use of maladaptive ER strategies such as rumination or suppression. People with either disorder may see themselves as less effective in using adaptive strategies, such as CR (Daros et al., 2020). Some studies showed that BPD participants may use CR more often than those with MDD, while others did not find any differences between the disorders (Daros & Williams, 2019). Some studies don't even show differences between them in terms of ER difficulties (for example Carvalho Fernando et al., 2014). I found one study that also compared trait mindfulness measured with a questionnaire between patients with MDD, BPD (and obsessive-compulsive disorder, which are not discussed), and a control group (Didonna et al., 2019). The BPD group had lower scores than MDD on a subscale measuring non-reactivity to emotional stimuli, and both clinical groups had lower scores than HC on a subscale measuring non-judgmental approach.

The literature provides barely any studies that compared MDD and BPD during emotion regulation, especially on the neural level. In the study by De la Peña-Arteaga et al. (2021) a

group with MDD, group with BPD, and healthy controls were viewing negative and neutral pictures. Participants were supposed to simply observe, maintain evoked emotions, or regulate them using CR - distancing or reinterpretation (instructions involved both forms). The results showed decreased activity of the right vlPFC during CR in MDD and BPD groups, compared to HC. This region was used in functional connectivity analysis which revealed that both clinical groups had similarly reduced connectivity between vlPFC and right posterior temporal regions. Moreover, the MDD group had stronger connectivity between the vlPFC, right posterior temporal cortex, and left inferior temporal gyrus than the BPD group.

Another recent study compared these disorders during an ER task, in which participants were looking at negative or neutral pictures, maintaining emotions, or using reinterpretation to regulate emotions (Wainsztein et al., 2021). However, the authors were only looking at impact of adverse childhood experiences on ER. The results revealed that during CR more adverse experiences were related to heightened activation in MDD than in BPD in the anterior insula, IFG, caudate, hippocampus, amygdala, thalamus, superior parietal lobule, precuneus, and middle cingulate cortex. There were no significantly increased activations for BPD than MDD. This study suggests that despite shared clinical characteristics, MDD and BPD could have distinct neural underpinnings. Nevertheless, more studies are necessary to have a clearer understanding of MDD and BPD mechanisms.

2. Original study

2.1. Research rationale

As presented above, the available literature not only provides clinical characteristics of people with MDD and BPD, but also information about their cognitive-emotional functioning. They are distinct clinical disorders and present different symptoms, and yet, they share some of the characteristics, such as heightened negative affect, negativity bias, or dysfunctional processing of the self (Beatson & Rao, 2013). Also, in both disorders, activity of the prefrontal cortex in response to negatively valenced stimuli is often found to be diminished, and activity of the amygdala to be abnormally increased (e.g., Dell'Osso et al., 2010; Hamilton et al., 2012; R. H. Kaiser et al., 2015; Ruocco & Carcone, 2016). The disorders also often co-occur: MDD can be diagnosed in 61-83% of people with BPD, which may be one of the reasons for misdiagnoses of MDD or BPD (Gunderson et al., 2018). Despite this fact and numerous studies on each of these disorders, they are rarely directly compared. More comparisons of MDD and BPD could be the basis for improvement of available diagnostic methods and treatments.

Some of the available studies showed that in MDD and BPD the AM recall may be disturbed, resulting in overgeneral recall or remembering mostly negative events (e.g., (Renneberg et al., 2005; Rosenbach & Renneberg, 2015). However, no brain imaging studies up to date investigated both disorders together, and none investigated neural responses to positive memories in BPD. These gaps in literature limit our understanding of emotional functioning in these disorders. For example, people with BPD could have a different style of processing positively valenced information than people with depression. What is more, directly comparing AM recall between MDD and BPD could contribute to the improvement of therapeutic interventions which include methods of imagery rescripting or evaluation of autobiographical memories (such as the cognitive behavioral therapy, Çili & Stopa, 2019). Therefore, in the present study I asked women with MDD and with BPD to describe sad and happy memories and to recall these memories during an fMRI scan to measure neural responses. Those groups were never compared in such a task.

Previous studies of emotion regulation provided a strong base of neural mechanisms of processes involved in ER, especially when it comes to cognitive reappraisal. Both MDD and BPD are disorders of emotion regulation, however, the literature on ER in these disorders is limited. From a therapeutic perspective it is important to know if people with either disorder can effectively engage in adaptive regulatory strategies when instructed to. In the present

dissertation I asked participants to use either CR or MA strategies when faced with negatively valenced pictures.

In the following sections one neuroimaging experimental study is reported, which consisted of two tasks: an autobiographical memory recall task and an emotion regulation task. Three participant groups were recruited - women with depression, women with borderline personality disorder, and healthy control women. During the autobiographical memory task participants were recalling sad and happy memories and rating their emotional state and vividness of the memories. Participants also rated their memories on additional scales after the fMRI scan. During the emotion regulation task, they were asked to look at sadness-eliciting pictures and use a cognitive reappraisal strategy, a mindful acceptance strategy, or naturally view the stimuli. They rated their emotional state and how successful they were in following the strategies' instructions.

The presented research aimed to achieve the following goals:

- To investigate how emotionally valenced (sad and happy) memories are processed in MDD and BPD, on behavioral and neural levels.
- To investigate how different emotion regulation strategies (CR and MA) are processed in MDD and BPD, on behavioral and neural levels.
- To investigate how different or how similar MDD and BPD are in those two processes.

2.2. Hypotheses and research questions

Concerning the autobiographical memory task, I had the following hypotheses and research questions related to behavioral ratings of emotional state and vividness during the fMRI scan:

H1: Because in MDD and BPD self-referential, negative information is more likely to elicit negative emotions, I predicted that:

H1a: The MDD participants would rate their emotional state during the task as sadder after sad memories recall than the HC group.

H1b: The BPD participants would rate their emotional state during the task as sadder after sad memories recall than the HC group.

H2: Previous research showed that positive memories have a low impact on improving the emotional state of people with MDD. In BPD positive stimuli may not be processed as salient. Therefore, I anticipated that:

H2a: The MDD group would rate their emotional state during the task as less happy after happy memories recall as compared to the HC group.

H2b: The BPD group would rate their emotional state during the task as less happy after happy memories recall as compared to the HC group.

Q1: There are no available studies comparing MDD and BPD groups during AM recall. Therefore, I decided to investigate whether the groups would differ in terms of their emotional state and the vividness of recall after sad and happy memories.

Regarding the additional ratings of memories done on paper after the fMRI scan, I constructed the following hypotheses:

H3: Previous research showed that in MDD and BPD negative memories may be more concordant with the present self-views and more important for the present life than the positive memories. Moreover, people with BPD are characterized by emotional hyperreactivity and impulsivity, while people with MDD are more prone to stable negative emotional reactions. I predicted that:

H3a: The MDD group would rate their sad memories as more arousing than the HC group.

H3b: The BPD group would rate their sad memories as more arousing than the HC group.

H3c: The BPD group would rate their sad memories as more arousing than the MDD group.

Concerning the neuroimaging results of the AM task, I constructed the following hypotheses and research questions:

H4: Previous research showed that in MDD and BPD emotional AM recall provoked stronger emotional reactions than in HC. It was also shown before that strong emotions are often related to a higher level of vividness during recall. Therefore, I predicted that:

H4a: For sad memories, MDD group would show greater activation of regions processing emotional content of AMs (the amygdala, insula, and ACC) and visual imagery (the occipital cortex and precuneus) when compared to the healthy control group.

H4b: For sad memories, BPD group would show greater activation of regions processing emotional content of AMs (the amygdala, insula, and ACC) and visual imagery (the occipital cortex and precuneus) when compared to the healthy control group.

H4c: For sad memories, BPD group would show greater activation of regions processing emotional content of AMs (the amygdala, insula, and ACC) and visual imagery (the occipital cortex and precuneus) when compared to the MDD group.

Q2: In both disorders, individuals are less sensitive to positive emotional information. However, no studies compared the recall of positive AMs between MDD and BPD. Also, only several studies examined positive memories in MDD and none in BPD, thereby the knowledge of differences between these groups and healthy controls is limited. I wanted to explore whether:

Q2a: The MDD group would differ significantly in processing happy memories from the HC group.

Q2b: The BPD group would differ significantly in processing happy memories from the HC group.

Q2c: The MDD group would differ significantly in processing happy memories from the BPD group.

Q3: Both disorders present disturbed self-views and beliefs and show disrupted processing of self-relevant information. Given the importance of memories for the self, I decided to explore:

Q3a: Whether sad and happy AMs would be different from each other in terms of neural activation in regions processing the self (the vmPFC and PCC) across all groups.

Q3b: Whether sad and happy memories would differentiate between BPD and MDD groups in terms of neural activation in regions processing the self (the vmPFC and PCC).

Q4: As the literature is scarce on the topic of functional connectivity during AM recall, I wanted to explore functional connectivity for the pre-defined ROIs between sad and happy AMs recall.

Q5: For the same reason I wanted to explore possible between- and within-group differences in functional connectivity for the pre-defined ROIs between sad and happy AMs recall.

Concerning the emotion regulation task, I had the following hypotheses and research questions related to behavioral ratings of emotional state and perceived success in following instructions during the fMRI scan:

H5: The clinical characteristics and literature show that people with MDD and BPD have stronger emotional responses to negatively valenced stimuli and have ER difficulties. Therefore, I hypothesized that:

H5a: The MDD group would rate their emotional state after both ER strategies taken together as sadder than HC.

H5b: The BPD group would rate their emotional state after both ER strategies taken together as sadder than HC.

Q6: The literature comparing the two ER strategies is inconsistent regarding subjective ratings of emotions after regulation and subjective ratings of success in implementing the instructions. I wanted to explore if:

Q6a: The CR and MA strategies would differ in subjective ratings of emotional state in all participants taken together.

Q6b: The CR and MA strategies would differ in subjective ratings of success in implementing their instructions in all participants taken together.

Q7: There are no previous studies comparing CR and MA in BPD or in MDD. I wanted to explore if:

Q7a: The CR and MA strategies would differ in ratings of emotional state and in ratings of success in the MDD group.

Q7b: The CR and MA strategies would differ in ratings of emotional state and in ratings of success in the BPD group.

Concerning the neuroimaging results of the emotion regulation task, I stated the following hypotheses and research questions:

H6: Previous studies showed that people with BPD have abnormally high activation of the amygdala and diminished activation of prefrontal regions in response to emotional stimuli and during distancing. I expected that during CR the BPD group would have lower activation of the PFC regions, especially the DLPFC, DMPFC, VLPFC, than the HC group. They would also have higher activation within the amygdala and insula than HC.

H7: As the literature assumes that in depression limbic and prefrontal regions have abnormal functional connectivity, I hypothesized that during both ER strategies taken together there will be a weaker negative functional connectivity between the limbic (amygdala, insula) and prefrontal (ACC, VLPFC, DLPFC, and DMPFC) regions in the MDD group than in HC.

H8: For the same above-mentioned reason I assumed that during both ER strategies taken together there will be a weaker negative functional connectivity between the limbic (amygdala, insula) and prefrontal (ACC, VLPFC, DLPFC, and DMPFC) regions in the BPD group than in HC.

Q8: The literature on CR in MDD is inconsistent when it comes to engagement of prefrontal cortex. I wanted to explore whether participants with MDD would differ significantly from the HC group during CR.

Q9: There are only two studies comparing MDD and BPD groups during CR. Therefore, I wanted to explore if the clinical groups would be significantly different from each other during CR.

Q10: No studies compared MDD, BPD, and HC during MA. Therefore:

Q10a: I wanted to explore if the MDD group would be significantly different during MA regulation from the HC.

Q10b: I wanted to explore if the BPD group would be significantly different during MA regulation from the HC.

Q10c: I wanted to explore if the clinical groups would be significantly different from each other during MA regulation.

Q11: The literature is scarce on the topic of functional connectivity between different ER strategies. I wanted to examine if there will be a significant difference across all participants in functional connectivity between the amygdala, insula, ACC, VLPFC, DLPFC, and DMPFC between CR and MA.

Q12: Due to the lack of literature on functional connectivity of the amygdala between MDD and BPD during ER. I wanted to explore if connectivity between the amygdala, insula, ACC, VLPFC, DLPFC, and DMPFC significantly differed between the clinical groups.

2.3. Methods

Data for the present doctoral thesis was gathered during two research projects. One project was funded by the National Centre for Research and Development (I.N.09, TP-49/2017/PW-PB) and was approved by the ethics committee at the Faculty of Psychology, University of Warsaw (Komisja ds. Etyki Badań Naukowych Wydziału Psychologii Uniwersytetu Warszawskiego). The second project was funded by the National Science Center Preludium research grant (UMO-2019/33/N/HS6/02126) and was approved by the Ethics and Bioethics Committee at the Cardinal Stefan Wyszyński University in Warsaw (identification number: KEiB-09/2020; Komisja Etyki i Bioetyki Uniwersytetu Kardynała Stefana Wyszyńskiego). The first project was designed as a longitudinal intervention study concerning only the MDD group and was terminated due to a prolonged technical problem with the MRI scanner. In the second project, the same tasks and procedures were used, and data was collected from the BPD and healthy control groups, which were matched to the MDD group.

2.3.1. Recruitment process

Three groups were recruited for the study: a group of women with major depressive disorder (MDD), a group of women with borderline personality disorder (BPD), and a group of healthy control women (HC). Participant recruitment process was conducted in two stages - through an online questionnaire and then through a thorough recruitment interview.

First, information about the study was posted on different fanpages and groups on Facebook, inviting women to fill an online screening questionnaire on a secured website. Because study groups were recruited separately (because they were recruited in different research projects), the online postings had different contents depending on a group of interest. In the case of the MDD group, the announcement contained descriptions of several symptoms of depression such as lower self-esteem, despondency, and sleep disturbances, and invited women who experienced those symptoms to participate. The announcement for the BPD group contained several symptoms of BPD such as frequent changes in an emotional state, impulsive behavior, and unstable and intense relationships. Additionally, the announcement invited women who already had a BPD diagnosis. The HC group announcement invited women with no history of psychiatric or neurological disorders and who did not participate in psychotherapy in the past 6 months.

The online recruitment questionnaire consisted of:

1) questions regarding the history of mental and neurological disorders, medication intake, psychotherapy experience, metal objects in the body, pregnancy, and claustrophobia, which were based on the inclusion and exclusion criteria (criteria are described below for each group; see Supplementary Material 5.2. for details of the questionnaire),
2) the Center for Epidemiologic Studies depression questionnaire (CES-D; Radloff, 1977). A brief 20-item measure, examining depressive symptoms in the past week,
3) the Borderline Personality Inventory (BPI; Leichsenring, 1999). A measure with 54 true/false statements which was used to examine BPD pathology. This questionnaire was added during the recruitment of the BPD and HC groups (therefore, there are no results of this questionnaire for the MDD group).

Participants were invited for the second stage of the recruitment process if they initially met the inclusion criteria based on the responses to the general questions and obtained appropriate results in relation to the cut-off scores on the CES-D and the BPI.

The CES-D has a cut-off score of 16 points meaning that any result lower than 16 does not indicate depressive symptoms. Therefore, women for the MDD group were invited if they had a score of 16 points or higher on the CES-D. The BPI has a cut-off score of 20 points meaning that any result lower than 20 does not indicate BPD symptoms. Hence, women for the BPD group were invited if they had a score of 20 points or higher on the BPI. Women for the HC group were invited to the study if they had a score lower than 16 on the CES-D and lower than 20 on the BPI. In total, 210 women were invited for the second stage of the recruitment process.

The second stage was a recruitment interview. In the case of the MDD group it was led by two psychiatrists and in the case of the BPD and HC groups it was led by two trained psychologists. All interviewers were female. At this stage, participants were given thorough information about the study and gave their written consent for participation. The following measures were employed during the interviews:

1) the same general questions regarding the characteristics of a participant as those used in the online recruitment questionnaire,
2) the MINI-International Neuropsychiatric Interview (MINI, V. 5.0.0; Sheehan et al., 1998) which was used to assess occurrence of different psychiatric disorders,
3) the Structured Clinical Interview for DSM-5 Personality Disorders (SCID-5-PD; First et al., 2016).

Based on each of the above measures an interviewer decided if a participant met all the inclusion criteria (described below). Each participant was informed about the outcome of the

interview and which diagnostic criteria she fulfilled. Participants were also provided with information about mental health clinics and professionals if they wished to seek professional help.

2.3.1.1. Inclusion and exclusion criteria

Based on the evidence that MDD and BPD are more prevalent in women than in men (Sansone & Sansone, 2011; Skodol & Bender, 2003), I decided to recruit only women in order to have homogenous groups.

General inclusion criteria for all participants were:

- female,
- right-handedness,
- age 18-50,
- proficiency in using the Polish language.

General exclusion criteria for all participants were:

- history of, or current psychotic disorders, bipolar disorder or eating disorders, assessed with the MINI interview,
- current manic episode, current alcohol or drug dependence requiring specialized treatment, assessed with the MINI,
- participation in psychotherapy in the last 6 months,
- history of neurological disorders or brain injuries, pregnancy, claustrophobia, metal objects in the body, and other contraindications for participation in an MRI study.

Specific inclusion criteria for the MDD group were:

- current depressive episode, assessed with the HAMD,
- no current intake of psychotropic medication or intake of either selective serotonin reuptake inhibitors (SSRI) or serotonin-norepinephrine reuptake inhibitors (SNRI).

Recruited were women with MDD who either did not use any antidepressant medication or used only SSRI or SNRI. This decision was based on the current treatment recommendations in Poland (Samochowiec et al., 2021), without limiting the possibility of successful group recruitment.

Specific exclusion criteria for the MDD group were:

- severe depressive episode and strong suicidal ideations, assessed with the HAMD and the MINI,
- changes in medication type or dosage in the last 4 weeks,
- co-occurring personality disorders, assessed with the SCID-5-PD.

Participants in the MDD group were recruited even if they had co-occurring anxiety disorders because anxiety is an inherent part of depression, and these disorders are most often co-occurring (Gotlib & Joormann, 2010).

Specific inclusion criteria for the group with BPD participants were:

- meeting criteria for borderline personality disorder, assessed with the SCID-5-PD,
- no current intake of psychotropic medication or intake of either SSRI, SNRI, or anticonvulsant medication.

Recruited were women with BPD who either did not use any psychiatric medication or used a maximum of 2 medications. These included SSRIs or SNRIs in order to maintain homogeneity with the MDD group, and mood-stabilizing anticonvulsant medication (lamotrigine and pregabalin) which are probably the most prescribed drugs for BPD patients in Poland (Katarzyna Kucharska, personal communication, March 28th, 2020, and April 22nd, 2021). This was decided in order to maintain homogeneity of the BPD group without limiting the possibility of a successful recruitment.

Specific exclusion criteria for the BPD group were:

- co-occurring antisocial or schizotypal personality disorders, assessed with the SCID-5-PD,
- current intake of antipsychotic medication and mood stabilizers other than anticonvulsants,
- changes in medication type or dosage in the past 4 weeks.

Participants in the BPD group were recruited even if they presented alcohol abuse, which was assessed with the MINI. It is a common characteristic of this disorder and makes it difficult to recruit only people without it (Dell'Osso et al., 2010). Participants presenting with symptoms of alcohol addiction were excluded.

Additionally, regarding the most often co-occurring conditions in BPD, participants with current mild or moderate symptoms of depression, anxiety disorders, or other personality disorders (except those stated in the exclusion criteria) were recruited (Dell'Osso et al., 2010).

Moreover, participants were excluded if they presented symptoms of schizotypal or antisocial personality disorders. The schizotypal PD was excluded because of its relation to schizophrenia-spectrum disorders and the possibility of individuals experiencing psychotic episodes (APA, 2010; Rosell et al., 2014). The antisocial PD was excluded due to its main characterization - disregard and violation of the rights of other people, and antagonism (APA, 2010). These characteristics could have possibly influenced the dropout of already recruited participants and disturbed the study processes.

Specific exclusion criterion for the healthy control group was:

- any history of psychiatric disorders.

All groups were matched based on age and years of education as closely as possible.

2.3.2. Participants

A total of 129 women were recruited for the study: 54 for the MDD group, 36 for the BPD group and 39 for the HC group. Initially, participants taking certain psychiatric medication were included in the study. However, before the analyses I decided to exclude those participants. The exact influence of SSRI, SNRI or anticonvulsant medicine on the studied processes is unknown, and there is no well-established method to control this variable. A simple 1-0 factor (where 1 would mean someone was taking medication, and 0 would mean they didn't) wouldn't be sufficient because participants were prescribed different dosages or substances. Currently, there are no valid conversion methods to unify the substances. Therefore, they were excluded from all the analyses to prevent the influence of medication on the results. A detailed flowchart representing participants recruited or excluded from the study at all stages is presented in Figure 7.

In the MDD group, 7 participants withdrew from the study after the recruitment interview and 3 participants dropped out after the behavioral part of the study (see below for a detailed description of the study procedure). 14 women were excluded from the analyses: 13 due to taking medication, and 1 because of damaged data files. The final MDD group consisted of 30 participants (age: 21-47, M = 28.2, SD = 6.76; years of education: M = 17.3, SD = 2.25). 10 women had co-occurring psychiatric disorders: 8 had dysthymia, 4 had current panic attacks with mild symptoms, 1 had agoraphobia, 2 had social phobia (see Table 1).

In the BPD group, 1 participant resigned after the recruitment interview and 3 resigned after the behavioral part of the study. 14 women were excluded from the analyses due to taking

medication. The final group consisted of 18 participants (age: 20-38, M = 26.17, SD = 5.06, years of education: M = 15.61, SD = 2.31). 16 women had co-occurring psychiatric disorders: 11 had a current depressive episode, 7 had dysthymia, 7 had current panic attacks with mild symptoms, 4 had agoraphobia, 7 had social phobia, 3 had obsessive-compulsive disorder, 2 had post-traumatic stress disorder, and 8 had general anxiety disorder. 10 women had co-occurring personality disorders: 2 had dependent PD, 3 had avoidant PD, 4 had paranoid PD, and 4 had obsessive-compulsive PD.

In the HC group, 3 participants resigned after the recruitment interview and 2 after the behavioral part of the study. In total 34 participants were included in the healthy control sample (age: 19-44, M = 28.09, SD = 6.31; years of education: M = 17.13, SD = 2.95).

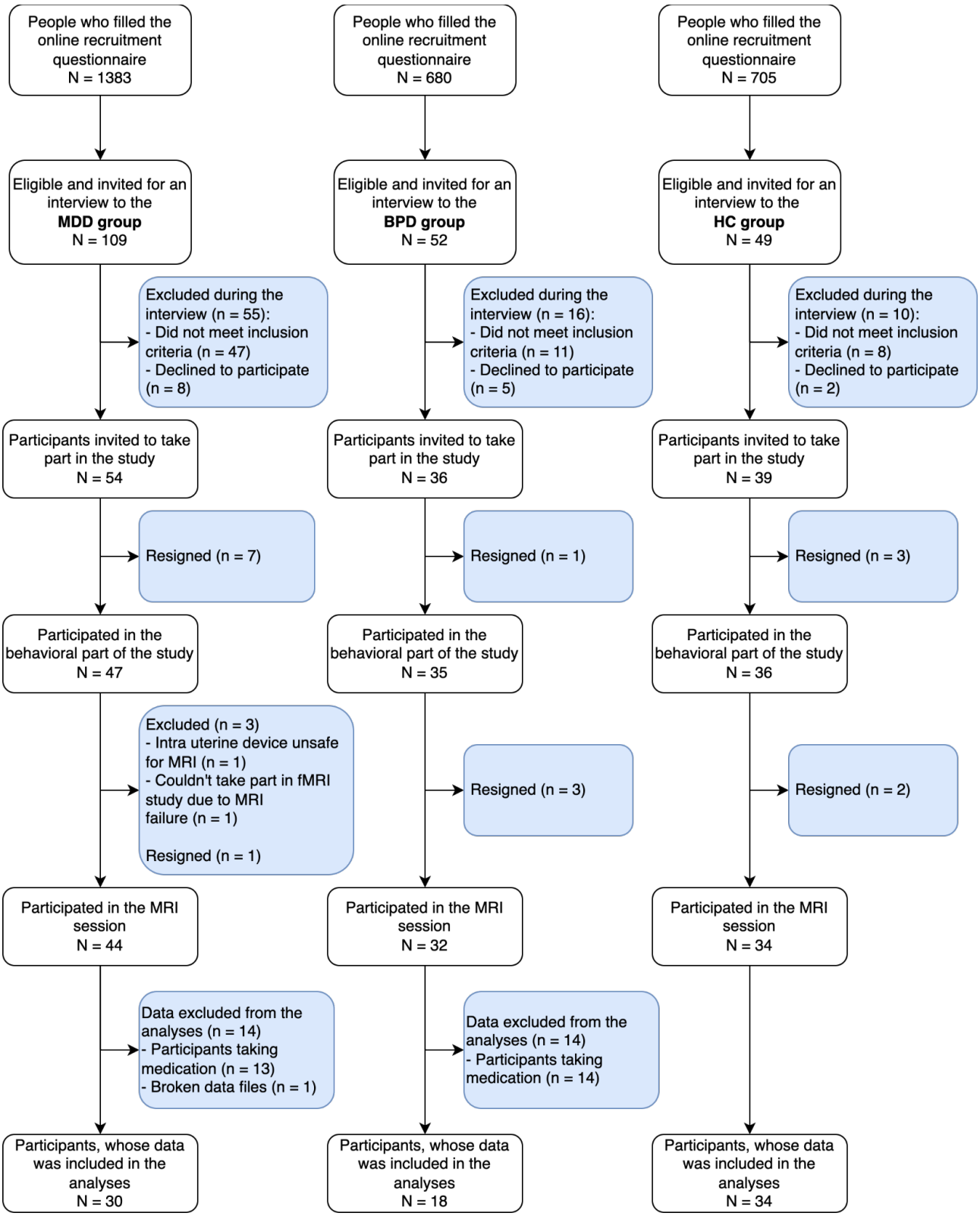


Figure 7. Flowchart representing recruitment process. MDD - major depressive disorder, BPD - borderline personality disorder, HC - healthy control.

Table 1. Demographic and clinical characteristics of the participants. MDD – major depressive disorder, BPD – borderline personality disorder, HC – healthy control, SD – standard deviation.

	MDD (N = 30)			BPD (N = 18)			HC (N = 34)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Demographic data									
Age	28.2	6.76	21-47	26.17	5.06	20-38	28.09	6.31	19-44
Years of education	17.3	2.25	12-22	15.61	2.31	11-19	17.13	2.95	11-24
	n	*%*		*n*	*%*				
Comorbid psychiatric disorders									
Depressive episode	-	-		11	61.11				
Dysthymia	8	26.67		7	38.89				
Panic attacks	4	13.33		7	38.89				
Agoraphobia	1	3.33		4	22.22				
Social phobia	2	6.67		7	38.89				
Obsessive-compulsive disorder	0	0		3	16.67				
Post-traumatic stress disorder	0	0		2	11.11				
General anxiety disorder	0	0		8	26.67				
Comorbid personality disorders									
Dependent	-	-		2	11.11				
Avoidant	-	-		3	16.67				
Paranoid	-	-		4	22.22				
Schizoid	-	-		0	0				
Obsessive-compulsive	-	-		4	22.22				
Narcissistic	-	-		0	0				

2.3.3. Procedure

The study was divided into two meetings. During the first (behavioral) meeting participants were reminded about the study procedures and their right to withdraw from it at any time. Then they were asked to provide specific memories which were needed for one of the MRI tasks (autobiographical memory task; see 2.3.4.). The whole meeting lasted around 60 minutes.

The second (MRI) meeting took place within two weeks after the first one. At the beginning of the second meeting, participants filled out MRI safety forms. Then they were informed about all the stages of the experimental procedure and about the structure of each task. Participants also practiced how to execute instructions for the emotion regulation task (described below). The study began when they had no more questions and confirmed their

understanding of the instructions. The fMRI scanning session had the following order: localizer and field map acquisition, autobiographical task, a short break outside of the scanner, emotion regulation task (chapter 2.3.5.), and structural image acquisition. The scanning session took around 75 minutes. After the scanning session was finished participants were given the opportunity to take another short break and rest. Then they were asked to rate all the memories used in the autobiographical task using a pen-and-paper method. The second meeting lasted for around 120 minutes. Depending on a research project participants received financial compensation for completing all parts of the project - MDD participants received 300PLN (~66EUR), BPD and HC participants received 180PLN (~40EUR).

The MDD and HC groups came to the Institute of Experimental Biology for both meetings. Due to the COVID-19 pandemic, the BPD group came in person only for the second meeting while the memories for the autobiographical task were collected during a Skype call (https://www.skype.com/).

2.3.4. Autobiographical memory fMRI task

During the first (behavioral) meeting for the study all participants were asked to provide specific memories for the autobiographical memory task. This procedure had a form of a conversation during which participants were asked to provide 5 sad memories (SAD) in which sadness was a dominant emotion, 5 happy memories (HAPPY) in which happiness was a dominant emotion, and 5 neutral daily situations or routines (NEUTRAL) which elicited no emotions whether thinking about them or performing them. The recall of neutral memories was designed according to the previous studies (e.g., Keedwell et al., 2005; Young, Bodurka, et al., 2016), as a moment to take a break from emotional information. In the case of sad and happy memories participants were encouraged to briefly describe each memory in a few sentences but they had the freedom to say as much or as little as they wanted. In the case of neutral routines, they were asked for one-sentence-long descriptions. Participants were additionally instructed that the memories could have been from any time point in their life but had to be specific single events that lasted up to 1 day. In line with previous studies (Silvers et al., 2016), if participants had difficulty recalling memories, they were told that emotional memories usually involve family, friends, work, or school.

All descriptions were written down. Each memory was shortened to a cue and was implemented in the task to trigger active recall. Each cue was 2-5-word long and consisted of

essential information for a specific memory (see Supplementary Material 5.3. for examples of memories and their cues provided by three participants). A cueing method based on a pre-scan interview was used because it gives bigger control over the content of memories.

Prior to the MRI scanning session, participants received thorough information about the autobiographical memory task. They were told that during the task 2-5-word cues would be appearing on a screen based on full descriptions of their memories. Participants were told that while a cue was presented on the screen they should try and recall as many details of that corresponding memory as they could, including circumstances, surroundings, places, and people. They were also asked to try and recall what they felt during that time and to feel those emotions again. Additionally, participants were told that after a recall they will answer two questions and then have a moment to relax, during which they should try to clear their mind of all thoughts and feelings related to that memory. Short practice on how to respond to questions using response pads took place after the instructions for the emotion regulation task.

The scanning session for this task included 2 functional runs. The first run always included sad and neutral memories and the second run always included happy and neutral memories. Each run had 10 interleaved blocks in a fixed order (see Figure 8a), including 5 blocks with emotional memories and 5 blocks with neutral memories. The neutral events were the same for both runs but their order was randomized.

Each block (see Figure 8b) began with instruction and a memory cue, presented for 22s. The instruction for sad or happy memories was as follows: “Recall [memory cue]. Recall as many details as possible. Feel the same emotions as back then.” (PL: *Przypomnij sobie [wskazówka] Przypomnij sobie jak najwięcej szczegółów. Poczuj te same emocje co wtedy*). The instruction for neutral memories was as follows: “Recall the last time when you [memory cue]. Recall as many details as possible.” (PL: *Przypomnij sobie jak ostatnio [wskazówka]. Przypomnij sobie jak najwięcej szczegółów*).

The recall period was immediately followed by two questions (8s each), separated by a fixation cross (1s). The first question asked about emotions during recall (“What emotions did you feel while thinking about that memory?”; PL: *Jakie emocje odczuwałaś w trakcie myślenia o tym wspomnieniu?*), to which participants answered on a 9-point Likert scale (where 1 indicated strong sadness, 5 indicated a neutral state, 9 indicated strong happiness). The second question asked about the vividness of the memory (“How vividly did you recall the memory?”; PL: *Jak żywo przypomniałaś sobie to wspomnienie?*) and had a 7-point Likert scale (where 1 indicated “not vivid at all, I could not remember anything” and 7 indicated “extremely vivid, I could remember everything”). A block ended with a relaxation period (18s), during which

participants saw an instruction “Now relax and clear your mind of all thoughts and emotions” (PL: *Teraz odpręż się i oczyść umysł ze wszystkich myśli i emocji)*. After this part ended, the next block started.

Each block lasted 57 seconds. The experimental procedure was implemented using Presentation software (Neurobehavioral Systems, http://www.neurobs.com/).

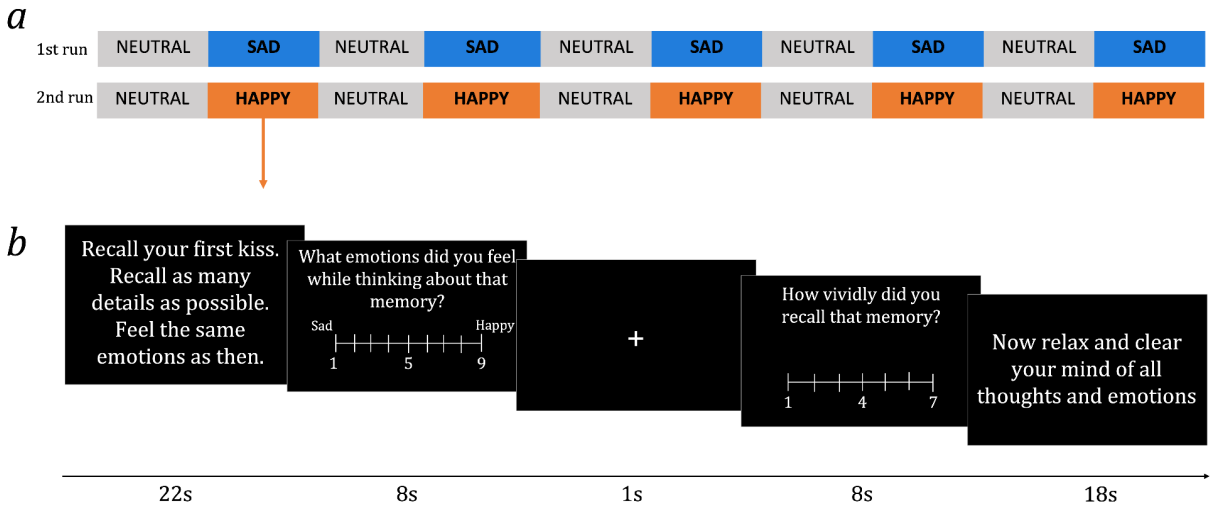


Figure 8. Experimental design of the autobiographical memory task. (a) Structure of the functional runs. The order of runs was fixed. Each run consisted of 10 blocks and lasted for around 10min. The same five neutral memories were repeated in both runs but their order was randomized. (b) Structure of a block. Each block started with a memory cue and instruction to recall all the details and emotions of this memory. Then participants answered two questions about their affective state during recall and the vividness of that memory. NEUTRAL - the recall of neutral memories, SAD - the recall of sad memories, HAPPY - the recall of happy memories.

After the MRI scanning sessions, participants were asked to rate all their memories on several scales in a pen-and-paper approach. These ratings were used in order to control whether sadness and happiness were the dominant emotions in sad and happy memories, respectively, and what other emotions were evoked by the memories. They used six 7-point Likert scales to indicate the intensity of basic emotions (happiness, surprise, sadness, anger, disgust, fear) in relation to each memory (1 on the scale indicated a very low level of emotion, and 7 indicated a high intensity of emotion). Moreover, 9-point Self-Assessment Manikin (Bradley and Lang, 1994) was used for two additional scales. Participants rated their emotional reaction evoked by a memory on an emotional valence scale (1 for “very sad/negative” and 9

for “very happy/positive”) and rated to what extent a memory made them emotionally aroused (1 for “not aroused” and 9 for “very aroused”) on an emotional arousal scale. Instructions for this task and an example page of this self-report are presented in Supplementary Materials 5.4.

In order to see if any group had objectively sadder or happier memories, 9 independent judges rated participants’ memories. Supplementary Material 5.5. provides a description of methods for this procedure, and the results of statistical analyses.

2.3.5. Emotion regulation fMRI task

Prior to the fMRI scanning session participants received training regarding this task. They were told that during the task they would have to follow three instructions. If they saw “Just watch” during the task, they were supposed to observe the presented stimuli in a natural way. “Change the meaning” instructed participants to “change their initial interpretation of the picture into a more positive one, in order to feel better while looking at it”. This instruction was consistent with cognitive behavioral therapy (Beck, 1964), which implements reappraisal in its program, and with previous work that approached positive reappraisal (e.g., Ochsner et al., 2004; Shiota & Levenson, 2009; Moser et al., 2014). “Be mindful and accepting” instructed participants to observe the pictures and simultaneously observe their thoughts, emotions, and physiological responses to stimuli, without judging them or trying to change them, but instead accepting them. This instruction was consistent with previous studies on mindful acceptance (Kober et al., 2019).

Participants were given examples for implementing the instructions and practiced how to follow them while looking at exemplary stimuli (not used in the main procedure). They also practiced how to answer the behavioral questions during the task with the use of a response pad. The scanning session started when participants had no more questions and confirmed their understanding of the instructions.

The emotion regulation task consisted of 4 types of blocks: cognitive reappraisal regulation with sad pictures (“Change the meaning” instruction; REAP), mindful acceptance regulation with sad pictures (“Be mindful and accepting” instruction; MIND), viewing of sad pictures (“Just watch” instruction; $VIEW_{SAD}$), and viewing of neutral pictures (the same instruction; $VIEW_{NEU}$). The VIEW conditions were designed here as control conditions in line with previous studies where participants naturally observed emotionally charged and neutral stimuli (e.g., Davis et al., 2018; Kober et al., 2019; Moser et al., 2014). In particular, the $VIEW_{NEU}$

condition served to balance out emotionally charged stimuli. REAP and MIND conditions with neutral pictures were not included in the design as it is difficult for the participants to understand how to implement these regulations for non-emotional stimuli and typically these conditions are omitted in ER research (e.g., Davis et al., 2018; Smoski et al., 2014).

Primarily the scanning session for this task consisted of 4 functional runs - two runs with REAP instruction (REAP run), and two with MIND instruction (MIND run). The order of runs was interleaved and semi-randomized. 48 participants started with REAP run (MDD: 18, BPD: 12, HC: 18), 34 participants started with MIND run (MDD: 12, BPD: 6, HC: 16). After data from all participants was gathered it was found out that some of the stimuli in one MIND run were duplicated in the second MIND run. Therefore, it was necessary to discard one MIND run and in order to balance obtained data - also one REAP run. Only data from the two first runs was used in the analyses. Each run had 10 interleaved blocks, including 4 REAP/MIND blocks, 2 $VIEW_{SAD}$ blocks, and 4 $VIEW_{NEU}$ blocks. The order of blocks was fixed (see Figure 9a).

Each block (see Figure 9b) began with an instruction (3s) for either REAP, MIND, or VIEW, followed by two pictures (each shown for 10s). The instruction was always visible underneath the stimulus as a reminder. After the regulation or the viewing period, two questions appeared (each for 8s), separated by a fixation cross (1s). Participants rated their current emotional state ("What emotions do you feel right now?"; on a 9-point Likert scale, where 1 indicated strong sadness, 5 indicated a neutral state and 9 indicated strong happiness) and their success in following the instructions ("Rate how successful you were in following the instruction"; on a 7-point Likert scale, where 1 indicated that they failed to execute the instruction and 7 indicated a full success). The block ended with a fixation cross (3s). Each block lasted 43s. The experimental procedure was implemented using Presentation software (Neurobehavioral Systems, http://www.neurobs.com/).

Each of the two functional runs of the task consisted of 80 images: 48 eliciting sadness and 32 neutral pictures. Sadness-eliciting pictures depicted crying people, funerals, elderly, homeless, people facing natural disasters, starving or wounded animals. Neutral stimuli depicted animals and people in neutral settings, expressing no emotions. 29 images were taken from the Nencki Affective Picture System (NAPS, Marchewka et al., 2014). Due to insufficient number of neutral and sadness-eliciting images in NAPS additional 51 pictures were chosen from image sharing websites under the Creativity Commons license.

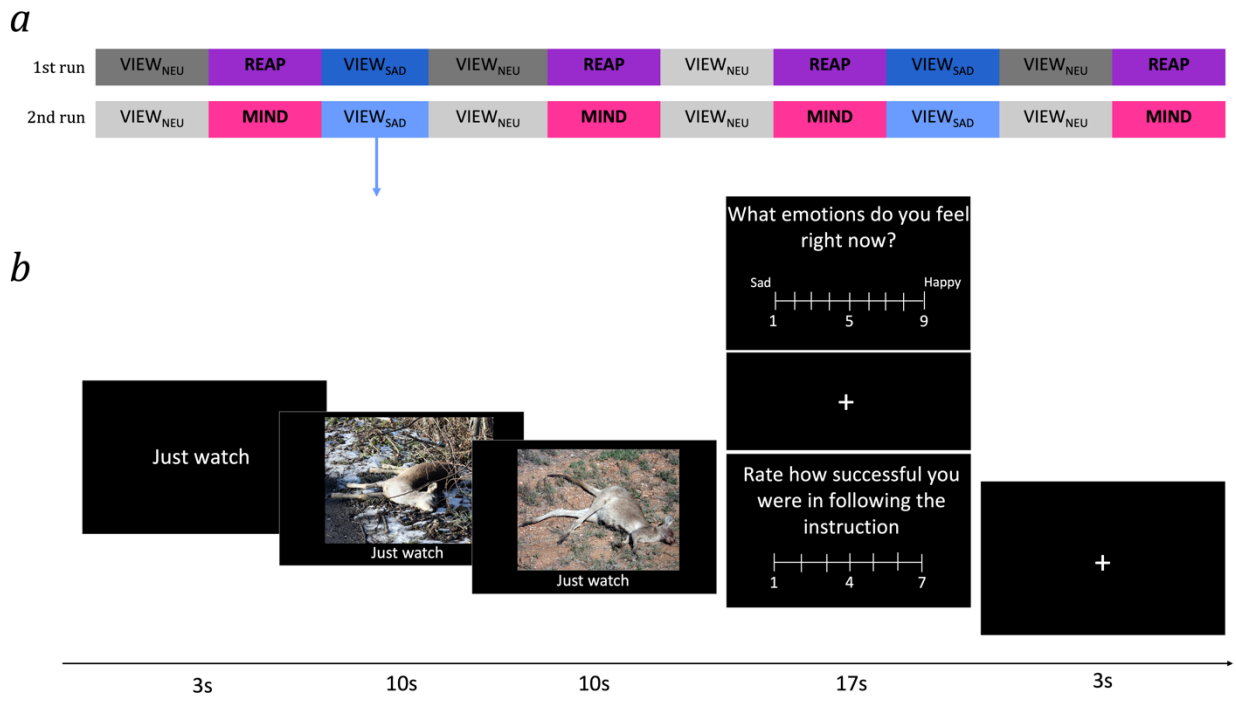


Figure 9. Experimental design of the emotion regulation task. (a) Structure of the functional runs. Each run consisted of 10 blocks and lasted for around 7min. 48 participants started with REAP run, 34 started with MIND run. (b) Structure of a block with sample pictures. Each block started with instruction, which was followed by two pictures (sad or neutral) with the instruction visible underneath them as a reminder. After the regulating or watching period participants answered two questions about their current affective state and their task performance. REAP - cognitive reappraisal regulation, MIND - mindful acceptance regulation, $VIEW_{NEU}$ - viewing of neutral pictures, $VIEW_{SAD}$ - viewing of sad pictures.

2.3.6. MRI data acquisition

Magnetic resonance data were acquired using a 3T Siemens Magnetom Trio scanner (Siemens Medical Solutions) equipped with a 32-channel head coil. The following images were acquired during a single scanning session: a structural localizer image, first field map magnitude image (TR = 488ms, TE = 7.46ms, flip angle = 60°, voxel size = 3x3x2.5mm, field of view = 216mm), first field map phase image (TR = 488ms, TE = 5ms, flip angle = 60°, voxel size = 3x3x2.5mm, field of view = 216mm), first 2 series of functional EPI images (45 slices, slice thickness = 2.5mm, TR = 2500ms, TE = 30ms, flip angle = 90°, field of view = 216mm, voxel size = 3x3x2.5mm), second field map magnitude and phase image (same parameters), second 4 series of functional EPI images (the same parameters), structural T1-weighted image (176 slices, slice thickness = 1mm, TR = 2530ms, TE = 3.32ms, flip angle = 7°, field of view = 256mm,

voxel size = 1x1x1mm). Field map images were acquired twice, separately for each task, due to participants taking a break during the scanning session outside of the MRI machine.

2.3.7. Behavioral data analysis

2.3.7.1. Analysis of demographic and clinical questionnaires data

Two 3x1 analysis of variance (ANOVA) models were used to check for differences between the groups in age and years of education. Responses from the CES-D and BPI questionnaires were analyzed using two rank-based nonparametric Kruskal-Wallis H tests. Pairwise comparisons were performed using Dunn test and Holm's correction for multiple comparisons.

2.3.7.2. Analysis of behavioral ratings during the autobiographical memory task

First, I wanted to check if there were differences between ratings of neutral memories depending on a run, because these memories were repeated. To do this I used aligned rank transform for nonparametric repeated measures ANOVA (Fawcett & Salter, 1984; Wobbrock et al., 2011) in two 3x2 models (one for emotions ratings and one for vividness ratings) with group (MDD, BPD, HC) as a between-subject variable and condition (2 x neutral memories) as a within-subject variable. As there were no significant differences between the conditions, their ratings were averaged and used as a one condition in the following analyses.

In the analysis I planned to verify two hypotheses and answer one research question. In order to see if MDD and BPD groups rated their emotional state during the task as sadder after sad AMs than the HC group (H1) I planned to directly compare MDD and HC (H1a), and BPD and HC (H1b) groups in the sad AMs condition using one-sided Wilcoxon-Mann-Whitney U tests. To verify if MDD and BPD groups will rate their emotional state as less happy after happy AMs than the HC group (H2) I planned to directly compare MDD and HC (H2a), and BPD and HC (H2b) groups in the happy AMs condition using one-sided Wilcoxon-Mann-Whitney U tests. To investigate whether MDD and BPD groups differed in terms of their emotional state and vividness ratings after sad and happy memories (Q1) I planned to directly compare the groups in both conditions using two-sided Wilcoxon-Mann-Whitney U test. As these tests were planned beforehand, they were not corrected for multiple comparisons (Wickens & Keppel, 2004).

For the remaining analyses aligned rank transform for nonparametric repeated measures ANOVA (Fawcett & Salter, 1984; Wobbrock et al., 2011) was used in a 3x3 model, with group (MDD, BPD, HC) as a between-subject variable, and condition (sad, happy, and neutral memories) as a within-subject variable. Two separate models were used for each of the behavioral questions - question about emotional state during recall and question about vividness of a memory. Post hoc tests were corrected using Holm's correction for multiple comparisons. Described analyses were performed in R Studio (RStudio Team, 2019, http://www.rstudio.com/), with the use of *ARTool* (Kay et al., 2021; Wobbrock et al., 2011) and *emmeans* (Lenth, 2019) packages.

2.3.7.3. Analysis of behavioral ratings of memories on additional scales

In the analysis I planned to verify two hypotheses. In order to examine if MDD and BPD groups rated their sad AMs as more arousing than the HC group (H3) I planned to directly compare MDD and HC (H3a), BPD and HC (H3b), and MDD and BPD (H3c) groups in the sad AMs condition using one-sided Wilcoxon-Mann-Whitney U tests. As these tests were planned beforehand, they were not corrected for multiple comparisons (Keppel and Wickens, 2004).

For the remaining analyses aligned rank transform for nonparametric repeated measures ANOVA (Fawcett & Salter, 1984; Wobbrock et al., 2011) was used in a 3x3 model with group as the between-subject factor (3 levels: MDD, BPD, HC) and condition as a within-subject factor (3 levels: sad, happy, and neutral memories) for each scale. Post hoc tests were corrected using Holm's correction for multiple comparisons. Described analyses were performed in R Studio (RStudio Team, 2019, http://www.rstudio.com/), with the use of *ARTool* (Kay et al., 2021; Wobbrock et al., 2011), and *emmeans* (Lenth, 2019) packages.

2.3.7.4. Analysis of behavioral ratings in the emotion regulation task

First, I wanted to compare ratings of $VIEW_{NEU\_REAP}$ and $VIEW_{NEU\_MIND}$ conditions, and $VIEW_{SAD\_REAP}$ and $VIEW_{SAD\_MIND}$ conditions. If there were no differences, I planned to average the ratings into two single conditions. I used aligned rank transform for nonparametric repeated measures analysis of variance (ANOVA) (Fawcett and Salter, 1984; Wobbrock et al., 2011) in four 3x2 models (separately for the two questions and for conditions) with group (MDD, BPD, HC) as a between-subject variable and condition ($VIEW_{NEU\_REAP}$ and $VIEW_{NEU\_MIND}$

or $VIEW_{SAD\_REAP}$ and $VIEW_{SAD\_MIND}$) as a within-subject variable. As there were significant differences between the conditions, the ratings were not averaged.

In order to see if MDD and BPD groups rated their emotional state during the task as sadder after ER in general than the HC group (H5), I planned to directly compare MDD and HC (H5a), and BPD and HC (H5b) groups in both ER strategies taken together using one-sided Wilcoxon-Mann-Whitney U tests. To investigate if CR and MA strategies differed in ratings of emotional state (Q6a) and of success in implementing their instructions (Q6b) I planned to directly compare the strategies across all participants using two-sided Wilcoxon-Mann-Whitney U tests. To explore if CR and MA ratings differed in the MDD (Q7a) or in the BPD (Q7b) groups I planned to compare the strategies using two-sided Wilcoxon paired t-tests. As these tests were planned beforehand, they were not corrected for multiple comparisons (Keppel and Wickens, 2004).

For the remaining analyses aligned rank transform for nonparametric repeated measures ANOVA (Fawcett and Salter, 1984; Wobbrock et al., 2011) was used in a 3x2x3 model, with group (MDD, BPD, HC) as a between-subject variable, and run (REAP, MIND) and condition (STRATEGY, $VIEW_{SAD}$, $VIEW_{NEU}$) as within-subject variables. Two separate models were used for each of the behavioral questions - question about emotional state and question about success in implementing task instructions. Post hoc tests were corrected using Holm's correction for multiple comparisons. Described analyses were performed in R Studio (RStudio Team, 2019, http://www.rstudio.com/), with the use of *ARTool* (Kay et al., 2021; Wobbrock et al., 2011) and *emmeans* (Lenth, 2019) packages.

2.3.8. fMRI data preprocessing

The DICOM series were converted to NIfTI format using Horos Bids Output Extension (https://github.com/mslw/horos-bids-output). Preprocessing of data from both tasks was performed with Statistical Parametric Mapping program (SPM12, http://www.fil.ion.ucl.ac.uk/spm). Functional images were preprocessed using standard steps (Poldrack et al., 2011): correction for distortions related to magnetic field inhomogeneity using fieldmap images, correction for motion using realignment to the first acquired image, correction for differences between acquired slices, coregistration of the anatomical image to the mean functional image, normalization to the MNI space with 2 x 2 x 2 mm voxels and smoothing with 6 mm FWHM Gaussian kernel. To identify additional sources of movement

artifacts in the functional images, the Artifact Detection Toolbox (ART, https://www.nitrc.org/projects/artifact_detect) was used, with a translation threshold of 2 mm and a rotation threshold of 0.04 radians. Images with motion exceeding these thresholds were considered outliers and were regressed out in the 1st level models. No participants had more than 20% of outliers and therefore no one was excluded from further analysis.

13 participants with MDD and 14 participants with BPD who were taking psychiatric medication during the study were excluded from the analyses. Also, one additional participant from the MDD group was excluded due to broken data files. Therefore, analyses were performed on 30 participants with MDD, 18 with BPD, and 34 healthy controls.

2.3.9. fMRI data analysis of the autobiographical memory task

At the first-level analysis general linear modeling (GLM) was used to model the blood-oxygen-level dependent signal (BOLD) for each participant. For each subject the GLM consisted of 2 scanning sessions, each containing 1 block regressor of interest: sad or happy memories (depending on a session). Neutral memories, relax after sad/happy memories, relax after neutral memories, behavioral questions, and a fixation cross between them, parameters of head motion, and ART motion regressors were added to the model as regressors of no interest. All the regressors related to the task were convolved with a standard hemodynamic response function (HRF). As each block (containing a memory, two behavioral questions with a fixation cross between them, and a relaxation period) lasted for 57s, the expected block-related signal changes had a period of ~120s. In order not to filter those possible changes out, the high-pass filter was set to 228s - a value of four lengths of a single block. I will first describe whole-brain GLM analyses, including those related to research question Q2. Then, I will describe ROI analyses for hypothesis H4 and research question Q3. Lastly, functional connectivity analyses, including those related to research questions Q4 and Q5, will be described.

Whole-brain GLM analysis. Several second-level analyses were performed, including planned a priori analyses to answer the research questions. To test the main effect of task (emotional AM recall), the average activity in sad and happy memories (SAD + HAPPY) was analyzed across all groups taken together, using a one-sample t-test. A paired t-test was used to identify regions activated specifically by sad or by happy AMs across all participants (SAD > HAPPY and HAPPY > SAD contrasts). To test the main effect of group across emotional recall responses between the groups were contrasted for the average effect of sad and happy AMs

(SAD + HAPPY) using a one-way ANOVA model. A flexible factorial model was used to test the interaction with group (MDD, BPD, HC) as the between-subject factor and condition (SAD, HAPPY) as the within-subject factor. To test whether the groups differed in neural processing of happy memories (Q2) I planned to directly compare MDD and HC (Q2a), BPD and HC (Q2b), and MDD and BPD (Q2c) groups using three two-sample t-tests. Further second-level random effects analyses were performed to localize significantly active regions across main contrasts of interest.

Results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$, corrected for multiple comparisons using the family-wise error (FWE) rate. All reported brain regions are labeled according to the automated anatomical labeling (AAL2) atlas (Rolls et al., 2015) applied in bspmview (https://www.bobspunt.com/bspmview).

Regions of interest specification and analyses. Regions of interest (ROIs) were specified a priori for ROI and functional connectivity analyses (described below). They corresponded to the main brain regions implicated in AM recall based on previous meta-analyses and AM literature (e.g., Bonnici et al., 2018; Cabeza & St Jacques, 2007; Kim, 2012; Spreng et al., 2009; Svoboda et al., 2006). These ROIs were: vmPFC, hippocampus, amygdala, occipital cortex, precuneus, posterior and anterior cingulate cortices, insular cortex, and angular gyrus. Anatomical masks of these regions were taken from the AAL2 atlas, while the vmPFC mask was taken from a Neurovault collection (https://neurovault.org/images/132836/). These masks were used with the main effect of task model (SAD+HAPPY) in order to obtain significant peak activation coordinates for the centers of ROIs. The following regions and their corresponding coordinates were included in the final set of ROIs: right vmPFC (x = 4, y = 54, z = -14), left hippocampus (x = -20, y = -8, z = -12), right hippocampus (x = 18, y = -6, z = -16), left occipital cortex (x = -12, y = -102, z = 4), right occipital cortex (x = 20, y = -100, z = 6), left precuneus (x = -1, y = -50, z = 34), left PCC (x = -8, y = -50, z = 30), left ACC (x = -6, y = 24, z = 30), left insular cortex (x = -42, y = 18, z = -2), right insular cortex (x = 44, y = 24, z = -6), left angular gyrus (x = -60, y = -58, z = 26), and right angular gyrus (x = 62, y = -50, z = 30). These ROIs were used for the small-volume correction (SVC) analyses with a sphere of 12 mm radius centered on these coordinates. For the bilateral amygdala whole mask was used due to its small anatomical volume.

To test whether during sad AM recall MDD and BPD groups had higher activations in the amygdala, insula, ACC, occipital cortex, and precuneus during sad AMs recall than the HC group (H4a and H4b) one-tailed two-sample t-tests were performed. In order to see if the BPD group

had higher activation in the same ROIs than the MDD group during sad recall (H4c) a one-tailed two-sample t-test was performed. To test if sad and happy AMs differed from each other in terms of activation in the vmPFC and PCC (Q3a) I used a paired t-test to compare the conditions. To test whether sad and happy AMs differed between the clinical groups in terms of activation in the vmPFC and PCC (Q3b) I performed a flexible factorial analysis with a group as a between-subject factor and condition as a within-subject factor.

***Functional connectivity analysis*.** The CONN toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012) for SPM was used to perform task-based functional connectivity analyses. First level SPM files, including ART motion parameters, and normalized T-1 images were imported into the software. ROIs defined as spheres of 6mm radius centered on the above-mentioned peak coordinates were used as functional connectivity seeds. For the amygdalae two anatomical masks were used, taken from the AAL2 atlas. A denoising procedure was applied to data to remove confounding motion and physiological effects from the BOLD signal. Regressors for this procedure were: signals from white matter and cerebrospinal fluid, realignment parameters obtained from the SPM preprocessing, and ART movement covariates. Task effects were also included as regressors to avoid measuring connectivity caused by shared task-related co-activation responses between brain regions. The signal was high-pass filtered with 0.004 Hz that corresponds to a high-pass filter of 228s used in SPM.

Second-level analyses were performed using a weighted-GLM approach with bivariate correlations. ROI-to-ROI correlations were computed among all the defined ROIs for each effect of interest (which are described below). The ROIs were sorted automatically into clusters by a data-driven hierarchical clustering procedure called *complete-linkage clustering* (Sorensen, 1948) based on ROIs anatomical proximity and functional similarity (connectivity patterns; Nieto-Castanon, 2020). This allows to perform analyses between and within clusters and reduces the number of comparisons. The Functional Network Connectivity (FNC) multivariate parametric statistics with default settings applied were used for cluster-level inferences. This approach analyses between-network connectivity for all the clusters and within-network connectivity for all connections within those clusters. All FNC analyses were corrected with false discovery rate (FDR-corrected) at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for post-hoc comparisons between individual connections.

To test the main effect of task (emotional AM recall), the average connectivity in sad and happy memories (SAD + HAPPY) was analyzed across all groups taken together, using a one-sample t-test. To test possible differences in functional connectivity between sad and happy

AMs recall (Q4) I performed a two-tailed paired t-test for all the subjects taken together. To explore whether there were differences in functional connectivity between and within the groups for sad and happy AMs recall (Q5) I performed a main effect of group analysis and an interaction analysis. To test the main effect of group 3x1 ANOVA with the average effect of sad and happy AMs (SAD + HAPPY) was used. To test the interaction between group (MDD, BPD, HC) and condition (SAD, HAPPY) a 3x2 ANOVA model was used. I also wanted to test for connectivity between the groups for sad or happy recall separately, therefore I used two 3x1 ANOVA models.

2.3.10. fMRI data analysis of the emotion regulation task

At the first-level analysis GLM was used to model the BOLD signal for each participant. For each subject the GLM consisted of 2 scanning sessions, each consisting of 2 block regressors of interest: REAP or MIND strategy (depending on a session), and $VIEW_{SAD}$. Viewing neutral pictures, instructions, behavioral questions, a fixation cross between each condition, parameters of head motion and ART motion regressors were added to the model as regressors of no interest. All the regressors related to the task were convolved with a standard HRF. Each block (containing a brief instruction, two pictures, two behavioral questions, and a fixation cross) lasted for 43s. In order not to filter those possible changes out from the signal, the high-pass filter was set to 172s - a value of four lengths of a single block.

I will first describe whole-brain GLM analyses, including those related to research questions Q8, Q9, and Q10. Then, I will describe an ROI analysis for hypothesis H6. Lastly, functional connectivity analyses will be described including those related to hypotheses H7 and H8, and research questions Q11 and Q12.

Whole-brain GLM analysis. Several second-level analyses were performed, including planned a priori analyses to answer the research questions. First, I wanted to compare $VIEW_{SAD}$ conditions between the runs to check for possible differences. As this analysis revealed significant differences between them (see Supplementary Material 5.6. for results) they were not used as baseline conditions in statistical models that compared both ER strategies. To test the main effect of emotional regulation a one-sample t-test was used with a contrast REAP+MIND > 2x$VIEW_{SAD}$ to diminish the effect of looking at stimuli and of sadness. A paired t-test was used to identify regions activated specifically by CR or by MA across all participants (MIND > MIND and MIND > MIND contrasts). To test the main effect of group a one-way ANOVA

was used with a contrast REAP+MIND > 2x$VIEW_{SAD}$. In order to see which brain regions are modulated by the CR strategy, a paired t-test was performed with CR > $VIEW_{SAD}$ contrast. A similar model was used for the MA strategy, with MA > $VIEW_{SAD}$ contrast. A flexible factorial model was used to test for interaction between group (MDD, BPD, HC) and ER strategy (CR, MA). To examine if MDD participants differed from HC during CR (Q8) and if the MDD and BPD groups were different from each other during CR (Q9) I planned to compare the groups using two two-sample t-tests. To test if the three groups differed between each other during MA regulation (Q10) a one-way ANOVA was used. Further second-level random effects analyses were performed to localize significantly active regions across main effects of interest.

Results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$, corrected for multiple comparisons using the family-wise error (FWE) rate. All reported brain regions are labeled according to the automated anatomical labeling (AAL2) atlas (Rolls et al., 2015) applied in bspmview toolbox for SPM (https://www.bobspunt.com/bspmview).

***Regions of interest specification and analyses*.** Regions of interest were specified a priori for ROI and functional connectivity analyses (described below). Small-volume correction was used with a sphere of 12 mm radius centered on coordinates from two meta-analyses. Prefrontal ROIs, which are commonly reported as involved in CR, were taken from a meta-analysis by Berboth & Morawetz (2021, which included mainly CR studies): left IFG/vlPFC (x = -36, y = 39, z = -8), right superior frontal gyrus/dlPFC (x = 24, y = 28, z = 43), right MFG/dmPFC (x = 3, y = 29, z = 46; ROIs names are also taken from the study). Insula and ACC ROIs, which are often related to mindfulness, were taken from a meta-analysis by Messina et al. (2021, which focused on mindful acceptance studies): left insular cortex (x = -36, y = 26, z = -4), right ACC (x = 4, y = 28, z = 30). For the bilateral amygdala ROI whole masks were used, taken from the AAL2 atlas. To test whether during CR (CR > $VIEW_{SAD}$) BPD group had higher activation in the vlPFC, dlPFC, and dmPFC ROIs and lower activation in the amygdala and insula, when compared to the HC group (H6) a two-sample t-test was performed.

***Functional connectivity analysis*.** The CONN toolbox (Whitfield-Gabrieli and Nieto-Castanon, 2012) for SPM was used to perform task-based functional connectivity analyses. First level SPM files, including ART motion parameters, and normalized T-1 images were imported into the software. ROIs defined as spheres of 6mm radius centered on the above-mentioned peak coordinates were used as functional connectivity seeds. For the amygdalae two anatomical masks were used, taken from the AAL2 atlas. A denoising procedure implemented

in CONN was applied to data to remove confounding motion and physiological effects from the BOLD signal. Regressors for this procedure were: signals from white matter and cerebrospinal fluid, realignment parameters obtained from the SPM preprocessing, and ART movement covariates. Task effects were also included as regressors to avoid measuring connectivity caused by shared task-related co-activation responses between brain regions. The signal was high-pass filtered with 0.006 Hz that corresponds to a high-pass filter of 172s used in SPM.

Second-level analyses were performed using a weighted-GLM approach with bivariate correlations. ROI-to-ROI correlations were computed among all the defined ROIs for each effect of interest (which are described below). The ROIs were sorted automatically into clusters by a data-driven hierarchical clustering procedure called *complete-linkage clustering* (Sorensen, 1948) based on ROIs anatomical proximity and functional similarity (connectivity patterns; Nieto-Castanon, 2020). This allows to perform analyses between and within clusters and reduces the number of comparisons. The FNC multivariate parametric statistics (Jafri et al., 2008) with default settings applied were used for cluster-level inferences. This approach analyses between-network connectivity for all the clusters and within-network connectivity for all connections within those clusters. All FNC analyses were FDR-corrected at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for post-hoc comparisons between individual connections.

To test the main effect of emotional regulation, the average connectivity in ER (REAP+MIND > 2x$VIEW_{SAD}$) was analyzed across all groups taken together, using a one-sample t-test. To test for possible differences in functional connectivity between CR and MA (Q11) I performed a two-tailed paired t-test for all the subjects taken together. To test the main effect of group 3x1 ANOVA with the average effect of ER (REAP+MIND > 2x$VIEW_{SAD}$) was used. To test the interaction between group (MDD, BPD, HC) and condition (REAP, MIND) a 3x2 ANOVA model was used. To test whether there was a weaker negative functional connectivity between the limbic (amygdala, insula) and prefrontal (ACC, VLPFC, DLPFC, and DMPFC) regions in the MDD group than in HC during ER (REAP+MIND; H7) I performed a two-sample t-test. To test the same hypothesis but for BPD and HC groups (H8) also a two-sample t-test was used. To explore whether the clinical groups differed in functional connectivity between the ROIs (Q12) another two-sample t-test was used. I also wanted to test for connectivity between the groups for CR and MA separately, therefore I used two 3x1 ANOVA models.

2.4. Results

2.4.1. Demographics and clinical questionnaires

The groups did not significantly differ from each other neither in terms of age ($F(2, 79) = 0.69$, $p = 0.5$) nor in terms of years of education ($F(2, 79) = 2.68$, $p = 0.07$).

The Kruskal-Wallis H test showed a statistically significant difference in CES-D score between the groups ($\chi 2 = 59.49$, $p < 0.001$). Dunn's test for pairwise comparisons revealed that the MDD and BPD groups had significantly higher levels of depressive symptoms than the HC group (MDD vs HC: $Z = 7.18$, $p < .001$; BPD vs HC: $Z = 5.46$, $p < 0.001$). The clinical groups did not differ significantly ($Z = 0.69$, $p = 0.24$).

The Kruskal-Wallis H test showed a statistically significant difference in BPI score between BPD and HC groups ($\chi 2 = 34.83$, $p < 0.001$) – BPD participants had higher scores than the control group.

2.4.2. Behavioral ratings during the autobiographical memory task

Question about emotional state during recall. An analysis of emotions ratings for hypothesis H1, that the clinical groups would rate their sad AMs as sadder after the recall than the HC group, revealed that the MDD group rated their emotional state during sad memories as sadder than the HC group ($U = 365$, $p = 0.03$). A difference between BPD and HC group that was statistically insignificant ($U = 228$, $p = 0.07$). An analysis testing hypothesis H2, that the clinical groups would rate their happy AMs as less happy after recall than the HC group, showed that BPD group rated their emotional state as less happy than the HC group in the happy AMs condition ($U = 219$, $p = 0.05$), whereas there was no significant difference between the MDD and HC groups ($U = 521$, $p = 0.56$). An analysis for research question Q1, investigating if the clinical groups differed in terms of emotional state and vividness, did not reveal significant differences between the MDD and BPD groups for the sad ($W = 263.5$, $p = 0.89$) or the happy memories ($W = 349$, $p = 0.09$). These results are presented on Figure 10.

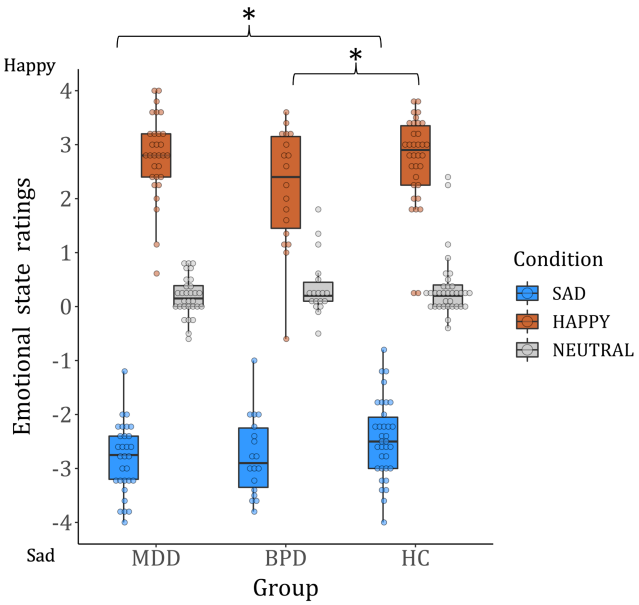


Figure 10. Results of hypotheses and research question regarding emotional state during recall. Significant results of the analyses for hypothesis testing are marked. The rating scale was changed from 1-9 points to -4-4 points for better visualization purposes. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *$p < 0.05$.

Remaining analyses revealed a significant main effect of group ($F(2,79) = 3.65$, $p = 0.03$, $\eta_p^2 = 0.08$) and main effect of condition ($F(2,158) = 675.32$, $p < 0.001$, $\eta_p^2 = 0.89$), but no significant interaction between group and condition ($F(4,158) = 1.84$, $p = 0.12$, $\eta_p^2 = 0.04$). Post hoc tests of the main effect of group showed that HC group rated their emotional state as happier in general than the BPD group ($T = -2.65$, $p = 0.03$), however there were no significant differences between MDD and BPD ($T = 1.32$, $p = 0.26$) and between MDD and HC groups ($T = -1.51$, $p = 0.26$) (Figure 11a). Post hoc tests of the main effect of condition showed that during sad memories emotional state was rated as sadder in comparison to happy ($T = -35.35$, $p < 0.001$) and to neutral ($T = -18.60$, $p < 0.001$) memories. Additionally, happy AMs elicited significantly happier emotions than the neutral AMs ($T = 16.75$, $p < 0.001$) (Figure 11b).

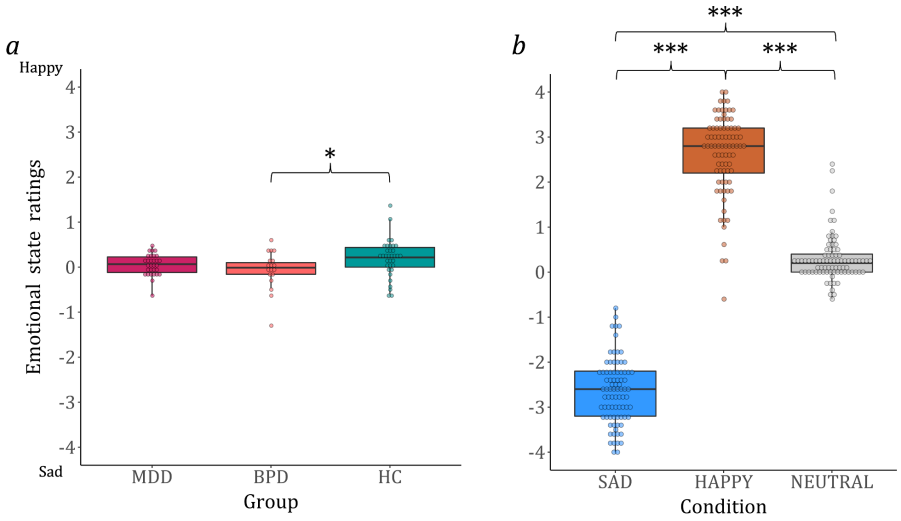


Figure 11. Behavioral results of the question about emotional state during recall. (a) Main effect of group. (b) Main effect of condition. The rating scale was changed from 1-9 points to -4-4 points for better visualization purposes. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *$p < 0.05$, *** $p < 0.001$

Question about vividness of recall. An analysis of the vividness ratings performed to answer Q1 did not reveal any significant differences between the MDD and BPD groups for sad ($W = 323$, $p = 0.26$) and happy ($W = 299.5$, $p = 0.53$) memories.

Remaining analyses showed a significant main effect of condition ($F(2,158) = 22.27$, $p < 0.001$, $\eta_p^2 = 0.21$) and interaction between group and condition ($F(4,158) = 2.89$, $p = 0.02$, $\eta_p^2 = 0.06$), but no significant main effect of group ($F(2,79) = 1.64$, $p = 0.19$, $\eta_p^2 = 0.04$). Post hoc tests of the main effect of condition showed that the sad AMs were rated as significantly less vivid than happy ($T = -6.22$, $p < 0.001$) and neutral ($T = -4.52$, $p < 0.001$) memories (Figure 12a). Post hoc tests of the interaction revealed that happy AMs were rated as significantly more vivid than sad AMs within the MDD ($U = 367.5$, $p < 0.001$) and HC groups ($U = 499.5$, $p < 0.01$), and that the HC group rated sad memories as less vivid than neutral ones ($U = 67.5$, $p < 0.01$) (Figure 12b). Remaining within- and between-group comparisons were found to be statistically insignificant.

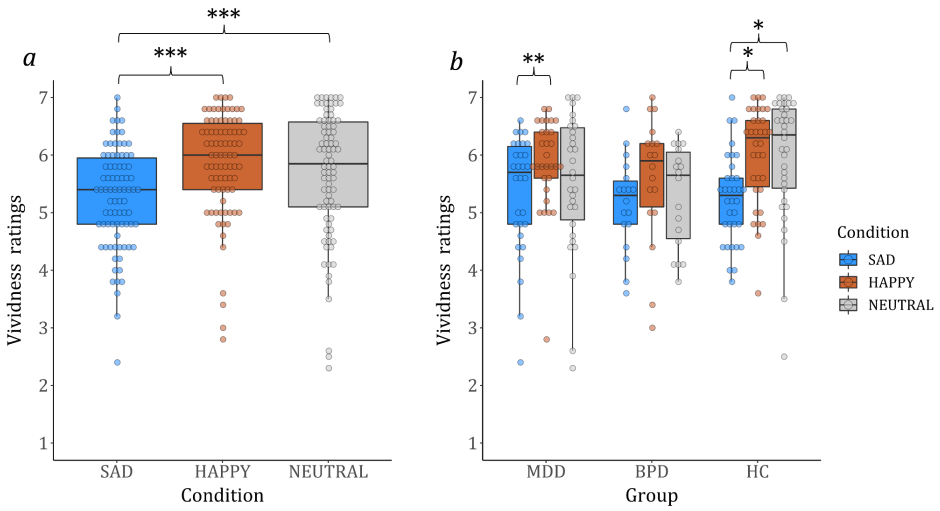


Figure 12. Behavioral results of the question about vividness of memories. (a) Main effect of condition. (b) Interaction between group and condition. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *$p < 0.05$, **$p < 0.01$, *** $p < 0.001$

2.4.3. Ratings of memories on additional scales

An analysis of arousal ratings for hypothesis H3, predicting that clinical groups will rate their sad AMs as more arousing than HC (H3a-b), revealed that sad memories were rated as more arousing in the MDD ($W = 777$, $p < 0.001$) and the BPD groups ($W = 497$, $p < 0.001$) than in the HC group. An analysis performed to test H3c, which assumed that the BPD group will rate sad AMs as more arousing than the MDD group, revealed that there was no significant difference between BPD and MDD groups in terms of arousal ratings of sad AMs ($W = 243$, $p = 0.2$) (Figure 13). Results of the remaining analyses are presented in the Table 2 and Figure 14a-u.

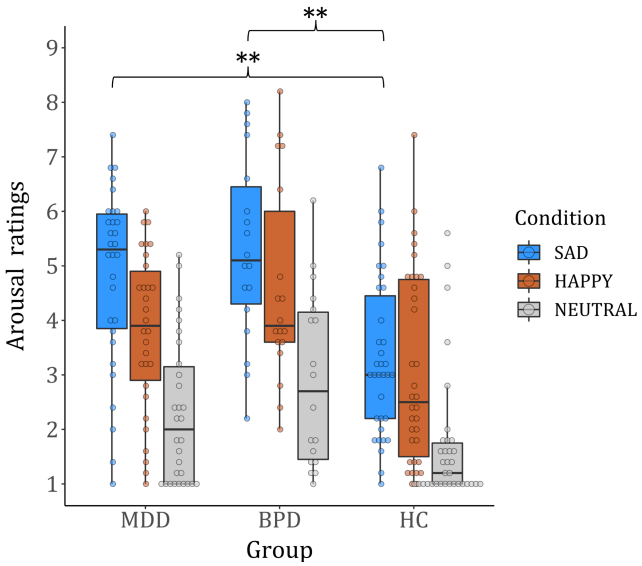


Figure 13. Behavioral results of arousal ratings for hypothesis H3 testing. Significant results of the analyses for hypothesis testing are marked. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. $^{**}p < 0.01$

Table 2. Behavioral results of the memories ratings. Significant *p* values are written in bold.

Rating scale	ANOVA main effects and interaction results				Post-hoc comparisons results		
	df, df res.	*F*	*p*	*η*2	Statistic	*p*	Direction of effect
Happiness ratings							
Main effect of group	2, 79	2.43	0.09	0.06			
Main effect of condition	2, 158	441.5	**< 0.001**	0.84			
SAD VS NEUTRAL					*T* = -12.54	**< 0.001**	SAD < NEUTRAL
HAPPY VS NEUTRAL					*T* = 16.47	**< 0.001**	HAPPY > NEUTRAL
SAD VS HAPPY					*T* = -29.01	**< 0.001**	SAD < HAPPY
Group x Condition	4, 158	1.5	0.2	0.03			
Surprise ratings							
Main effect of group	2, 79	16.47	**< 0.001**	0.29			
MDD VS HC					*T* = 4.32	**< 0.001**	MDD > HC
BPD VS HC					*T* = 5.2	**< 0.001**	BPD > HC
MDD VS BPD					*T* = -1.45	0.15	
Main effect of condition	2, 158	205.39	**< 0.001**	0.72			
SAD VS NEUTRAL					*T* = 17.16	**< 0.001**	SAD > NEUTRAL
HAPPY VS NEUTRAL					*T* = 16.81	**< 0.001**	HAPPY > NEUTRAL

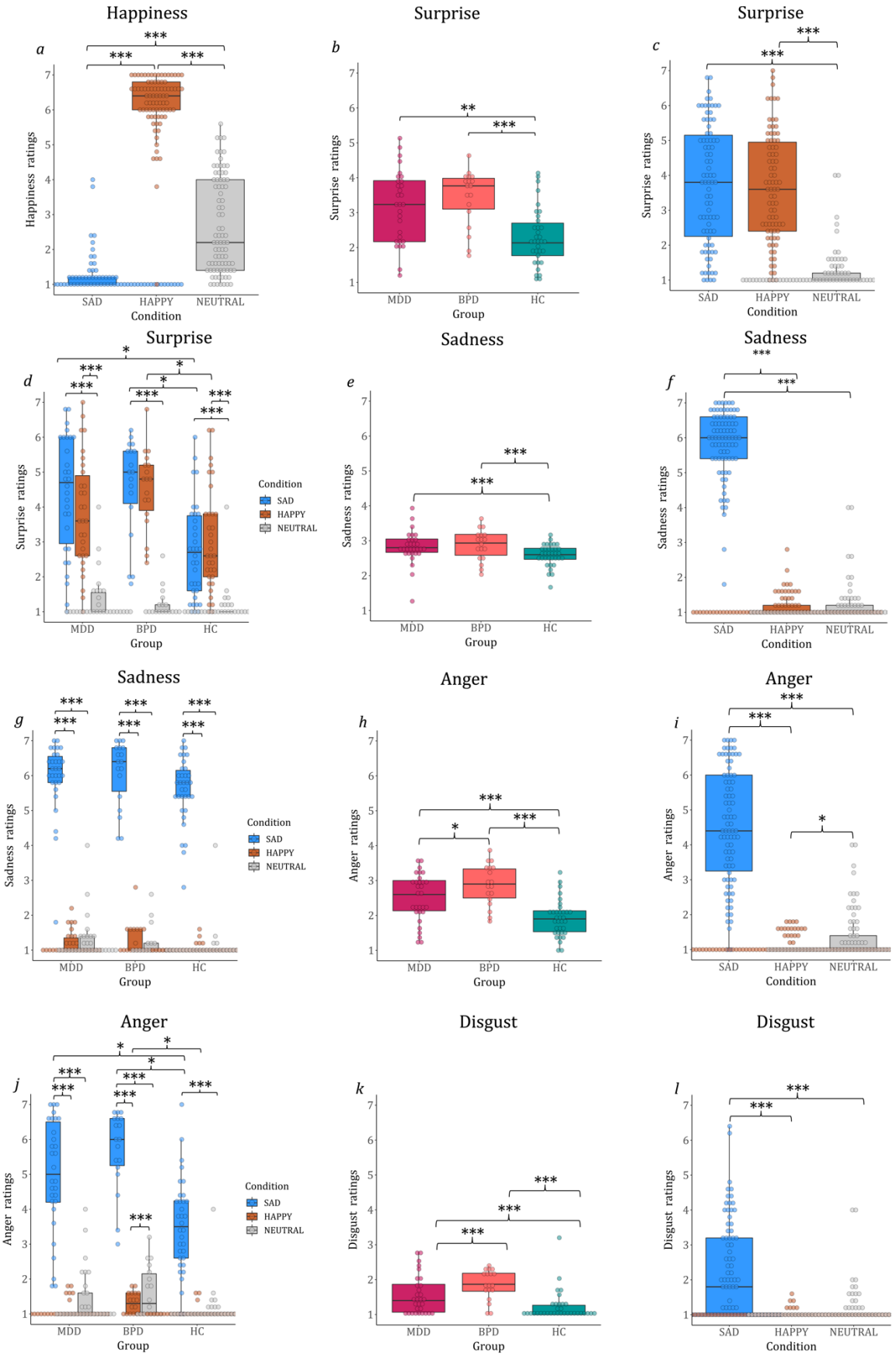
Rating scale	ANOVA main effects and interaction results				Post-hoc comparisons results		
	df, df res.	*F*	*p*	$\eta 2$	Statistic	*p*	Direction of effect
SAD VS HAPPY					*T* = 0.35	0.73	
Group x Condition	4, 158	11.54	**< 0.001**	0.23			
MDD SAD VS MDD NEUTRAL					*U* = 435	**< 0.001**	MDD SAD > MDD NEUTRAL
MDD HAPPY VS MDD NEUTRAL					*U* = 435	**< 0.001**	MDD HAPPY > MDD NEUTRAL
MDD SAD VS MDD HAPPY					*U = 145*	1	
BPD SAD VS BPD NEUTRAL					*U* = 171	**< 0.001**	BPD SAD > BPD NEUTRAL
BPD HAPPY VS BPD NEUTRAL					*U* = 171	**< 0.001**	BPD HAPPY > BPD NEUTRAL
BPD SAD VS BPD HAPPY					*U* = 69.5	1	
HC SAD VS HC NEUTRAL					*U* = 460	**< 0.001**	HC SAD > HC NEUTRAL
HC HAPPY VS HC NEUTRAL					*U* = 550	**< 0.001**	HC HAPPY > HC NEUTRAL
HC SAD VS HC HAPPY					*U* = 291	1	
MDD SAD VS HC SAD					*W* = 785	**0.03**	MDD SAD > HC SAD
BPD SAD VS HC SAD					*W* = 505.5	**0.01**	BPD SAD > HC SAD
MDD SAD VS BPD SAD					*W* = 258	1	
MDD HAPPY VS HC HAPPY					*W* = 663	0.8	
BPD HAPPY VS HC HAPPY					*W* = 481.5	**0.01**	BPD HAPPY > HC HAPPY
MDD HAPPY VS BPD HAPPY					*W* = 192	0.16	
MDD NEUTRAL VS HC NEUTRAL					*W* = 581.5	1	
BPD NEUTRAL VS HC NEUTRAL					*W* = 356.5	1	
MDD NEUTRAL VS BPD NEUTRAL					*W* = 268.5	1	
Sadness ratings							
Main effect of group	2, 79	19.85	**< 0.001**	0.33			
MDD VS HC					*T* = 5.13	**< 0.001**	MDD > HC
BPD VS HC					*T* = 11.51	**< 0.001**	BPD > HC
MDD VS BPD					*T* = -0.98	0.33	
Main effect of condition	2, 158	317.89	**< 0.001**	0.8			
SAD VS NEUTRAL					*T* = 22.03	**< 0.001**	SAD > NEUTRAL
HAPPY VS NEUTRAL					*T* = 1.43	0.15	
SAD VS HAPPY					*T* = 20.6	**< 0.001**	SAD > HAPPY
Group x Condition	4, 158	4.1	**0.003**	0.09			
MDD SAD VS MDD NEUTRAL					*U* = 465	**< 0.001**	MDD SAD > MDD NEUTRAL

Rating scale	ANOVA main effects and interaction results				Post-hoc comparisons results		
	df, df res.	*F*	*p*	*η*2	Statistic	*p*	Direction of effect
MDD HAPPY VS MDD NEUTRAL					*U* = 50.5	1	
MDD SAD VS MDD HAPPY					*U* = 68	**< 0.001**	MDD SAD > MDD HAPPY
BPD SAD VS BPD NEUTRAL					*U* = 171	**< 0.001**	BPD SAD > BPD NEUTRAL
BPD HAPPY VS BPD NEUTRAL					*U* = 38	1	
BPD SAD VS BPD HAPPY					*U* = 43.5	**< 0.001**	BPD SAD > BPD HAPPY
HC SAD VS HC NEUTRAL					*U* = 594	**< 0.001**	HC SAD > HC NEUTRAL
HC HAPPY VS HC NEUTRAL					*U* = 8.5	1	
HC SAD VS HC HAPPY					*U* = 5	**< 0.001**	HC SAD > HC HAPPY
MDD SAD VS HC SAD					*W* = 681	0.28	
BPD SAD VS HC SAD					*W* = 417	0.24	
MDD SAD VS BPD SAD					*W* = 233.5	1	
MDD HAPPY VS HC HAPPY					*W* = 650	0.09	
BPD HAPPY VS HC HAPPY					*W* = 410.5	0.17	
MDD HAPPY VS BPD HAPPY					*W* = 247	1	
MDD NEUTRAL VS HC NEUTRAL					*W* = 658	0.26	
BPD NEUTRAL VS HC NEUTRAL					*W* = 372	0.26	
MDD NEUTRAL VS BPD NEUTRAL					*W* = 290.5	1	
Anger ratings							
Main effect of group	2, 79	38.81	**< 0.001**	0.5			
MDD VS HC					*T* = 6.43	**< 0.001**	MDD > HC
BPD VS HC					*T* = 8.11	**< .001**	BPD > HC
MDD VS BPD					*T* = -2.53	**0.01**	MDD < BPD
Main effect of condition	2, 158	328.15	**< 0.001**	0.8			
SAD VS NEUTRAL					*T* = 465	**< 0.001**	SAD > NEUTRAL
HAPPY VS NEUTRAL					*T* = -2.5	**0.01**	HAPPY < NEUTRAL
SAD VS HAPPY					*T* = 22.79	**< 0.001**	SAD > HAPPY
Group x Condition	4, 158	22.79	**< 0.001**	0.37			
MDD SAD VS MDD NEUTRAL					*U* = 465	**< 0.001**	MDD SAD > MDD NEUTRAL
MDD HAPPY VS MDD NEUTRAL					*U* = 16.5	0.07	MDD HAPPY < MDD NEUTRAL
MDD SAD VS MDD HAPPY					*U* = 16.5	**< 0.001**	MDD SAD > MDD HAPPY
BPD SAD VS BPD NEUTRAL					*U* = 171	**< 0.001**	BPD SAD > BPD NEUTRAL

Rating scale	ANOVA main effects and interaction results				Post-hoc comparisons results		
	df, df res.	*F*	*p*	$\eta 2$	Statistic	*p*	Direction of effect
BPD HAPPY VS BPD NEUTRAL					*U* = 14	**< 0.001**	BPD HAPPY < BPD NEUTRAL
BPD SAD VS BPD HAPPY					*U* = 14	**< 0.001**	BPD SAD > BPD HAPPY
HC SAD VS HC NEUTRAL					*U* = 496	**< 0.001**	HC SAD > HC NEUTRAL
HC HAPPY VS HC NEUTRAL					*U* = 14.5	0.6	
HC SAD VS HC HAPPY					*U* = 8	**< 0.001**	
MDD SAD VS HC SAD					*W* = 775	**0.002**	MDD SAD > HC SAD
BPD SAD VS HC SAD					*W* = 465	**< 0.01**	BPD SAD > HC SAD
MDD SAD VS BPD SAD					*W* = 201	0.8	
MDD HAPPY VS HC HAPPY					*W* = 570.5	0.3	
BPD HAPPY VS HC HAPPY					*W* = 540.5	**0.01**	BPD HAPPY > HC HAPPY
MDD HAPPY VS BPD HAPPY					*W* = 170.5	0.4	
MDD NEUTRAL VS HC NEUTRAL					*W* = 614.5	0.3	
BPD NEUTRAL VS HC NEUTRAL					*W* = 427	0.07	BPD NEUTRAL > HC NEUTRAL
MDD NEUTRAL VS BPD NEUTRAL					*W* = 221	0.8	
Disgust ratings							
Main effect of group	2, 79	50.55	**< 0.001**	0.56			
MDD vs HC					*T* = 5.82	**< 0.001**	MDD > HC
BPD vs HC					*T* = 9.85	**< 0.001**	BPD > HC
MDD vs BPD					*T* = -4.74	**< 0.001**	MDD < BPD
Main effect of condition	2, 158	79.69	**< 0.001**	0.5			
SAD VS NEUTRAL					*T* = 10.2	**< 0.001**	SAD > NEUTRAL
HAPPY VS NEUTRAL					*T* = -1.4	0.16	
SAD VS HAPPY					*T* = 11.6	**< 0.001**	SAD > HAPPY
Group x Condition	4, 158	32.5	**< 0.001**	0.45			
MDD SAD VS MDD NEUTRAL					*U* = 240	**< 0.001**	MDD SAD > MDD NEUTRAL
MDD HAPPY VS MDD NEUTRAL					*U* = 3	0.19	
MDD SAD VS MDD HAPPY					*U* = 5	**< 0.001**	MDD SAD > MDD HAPPY
BPD SAD VS BPD NEUTRAL					*U* = 153	**< 0.001**	BPD SAD > BPD NEUTRAL
BPD HAPPY VS BPD NEUTRAL					*U* = 2	**0.02**	BPD HAPPY < BPD NEUTRAL
BPD SAD VS BPD HAPPY					*U* = 4	**< 0.001**	BPD SAD > BPD HAPPY
HC SAD VS HC NEUTRAL					*U* = 94	0.09	

Rating scale	ANOVA main effects and interaction results				Post-hoc comparisons results		
	df, df res.	*F*	*p*	$\eta 2$	Statistic	*p*	Direction of effect
HC HAPPY VS HC NEUTRAL					*U* = 1.5	0.8	
HC SAD VS HC HAPPY					*U* = 2	**0.03**	HC SAD > HC HAPPY
MDD SAD VS HC SAD					*W* = 729	**0.004**	MDD SAD > HC SAD
BPD SAD VS HC SAD					*W* = 542.5	**< 0.001**	BPD SAD > HC SAD
MDD SAD VS BPD SAD					*W* = 153	0.2	
MDD HAPPY VS HC HAPPY					*W* = 530	0.8	
BPD HAPPY VS HC HAPPY					*W* = 321.5	0.8	
MDD HAPPY VS BPD HAPPY					*W* = 266.5	0.8	
MDD NEUTRAL VS HC NEUTRAL					*W* = 568.5	0.8	
BPD NEUTRAL VS HC NEUTRAL					*W* = 388.5	0.08	BPD NEUTRAL > HC NEUTRAL
MDD NEUTRAL VS BPD NEUTRAL					*W* = 227.5	0.8	
Fear ratings							
Main effect of group	2, 79	28.85	**< 0.001**	0.42			
MDD VS HC					*T* = 5.01	**< 0.001**	MDD > HC
BPD VS HC					*T* = 7.24	**< 0.001**	BPD > HC
MDD VS BPD					*T* = -2.86	**0.005**	MDD < BPD
Main effect of condition	2, 158	188.52	**< 0.001**	0.7			
SAD VS NEUTRAL					*T* = 18.3	**< 0.001**	SAD > NEUTRAL
HAPPY VS NEUTRAL					*T* = 6.11	**< 0.001**	HAPPY > NEUTRAL
SAD VS HAPPY					*T* = 12.19	**< 0.001**	SAD > HAPPY
Group x Condition	4, 158	19.72	**< 0.001**	0.33			
MDD SAD VS MDD NEUTRAL					*U* = 465	**< 0.001**	MDD SAD > MDD NEUTRAL
MDD HAPPY VS MDD NEUTRAL					*U* = 134.5	**0.01**	MDD HAPPY > MDD NEUTRAL
MDD SAD VS MDD HAPPY					*U* = 2	**< 0.001**	MDD SAD > MDD HAPPY
BPD SAD VS BPD NEUTRAL					*U* = 171	**< 0.001**	BPD SAD > BPD NEUTRAL
BPD HAPPY VS BPD NEUTRAL					U = 115	**< 0.001**	BPD HAPPY > BPD NEUTRAL
BPD SAD VS BPD HAPPY					*U* = 4	**< 0.001**	BPD SAD > BPD HAPPY
HC SAD VS HC NEUTRAL					*U* = 456	**< 0.001**	HC SAD > HC NEUTRAL
HC HAPPY VS HC NEUTRAL					*U* = 110.5	0.14	
HC SAD VS HC HAPPY					*U* = 33.5	**< 0.001**	HC SAD > HC HAPPY
MDD SAD VS HC SAD					*W* = 793	**< 0.001**	MDD SAD > HC SAD

Rating scale	ANOVA main effects and interaction results				Post-hoc comparisons results		
	df, df res.	*F*	*p*	$\eta 2$	Statistic	*p*	Direction of effect
BPD SAD VS HC SAD					*W* = 546	**< 0.001**	BPD SAD > HC SAD
MDD SAD VS BPD SAD					*W* = 163.5	0.34	
MDD HAPPY VS HC HAPPY					*W* = 638.5	0.34	
BPD HAPPY VS HC HAPPY					*W* = 490.5	**0.002**	BPD HAPPY > HC HAPPY
MDD HAPPY VS BPD HAPPY					*W* = 169.5	**0.04**	MDD HAPPY < BPD HAPPY
MDD NEUTRAL VS HC NEUTRAL					*W* = 578	0.34	
BPD NEUTRAL VS HC NEUTRAL					*W* = 409.5	**0.05**	BPD NEUTRAL > HC NEUTRAL
MDD NEUTRAL VS BPD NEUTRAL					*W* = 221.5	0.34	
Valence ratings							
Main effect of group	2, 79	7.32	**0.001**	0.16			
MDD VS HC					*T* = -1.59	0.12	
BPD VS HC					*T* = -3.82	**< 0.001**	BPD < HC
MDD VS BPD					*T* = 2.4	**0.04**	MDD > BPD
Main effect of condition	2, 158	668.06	**< 0.001**	0.89			
SAD VS NEUTRAL					*T* = -18.11	**< 0.001**	SAD < NEUTRAL
HAPPY VS NEUTRAL					*T* = 16.27	**< 0.001**	HAPPY > NEUTRAL
SAD VS HAPPY					*T* = -34.4	**< 0.001**	SAD < HAPPY
Group x Condition	4, 158	1.4	0.24	0.03			
Arousal ratings							
Main effect of group	2, 79	13.83	**< 0.001**	0.26			
MDD VS HC					*T* = 3.88	**< 0.001**	MDD > HC
BPD VS HC					*T* = 4.8	**< 0.001**	BPD > HC
MDD VS BPD							
Main effect of condition	2, 158	64.84	**< 0.001**	0.45			
SAD VS NEUTRAL					*T* = 10.61	**< 0.001**	SAD > NEUTRAL
HAPPY VS NEUTRAL					*T* = 7.44	**< 0.001**	HAPPY > NEUTRAL
SAD VS HAPPY					*T* = 3.17	**< 0.01**	SAD > HAPPY
Group x Condition	4, 158	2.11	0.08	0.05			


a
Happiness
Happiness ratings
Condition
SAD
HAPPY
NEUTRAL
b
Surprise
Surprise ratings
Group
MDD
BPD
HC
c
Surprise
Surprise ratings
Condition
d
Surprise
Surprise ratings
Group
Condition
e
Sadness
Sadness ratings
f
Sadness
Sadness ratings
g
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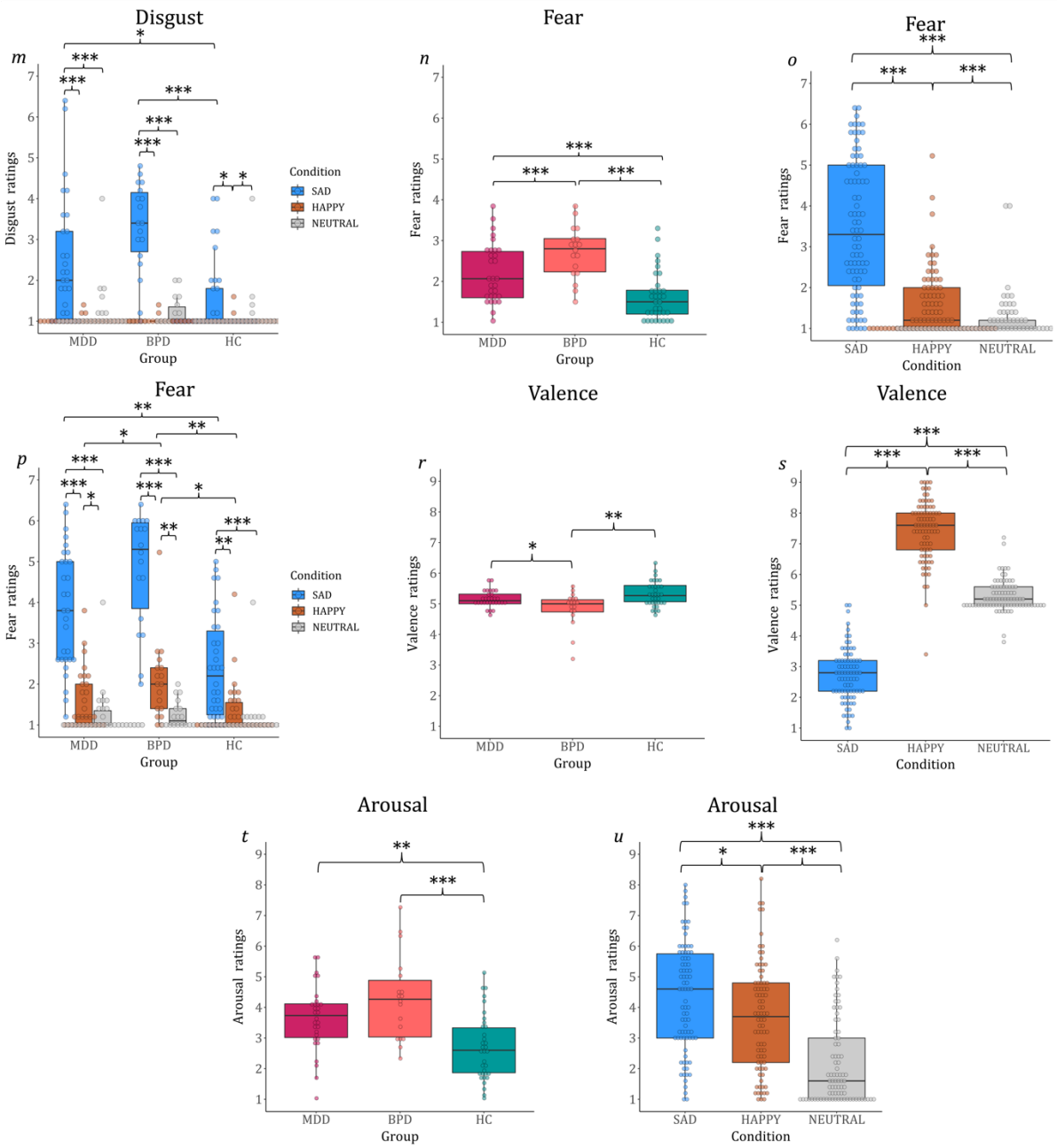

Figure 14. Behavioral results of memories ratings. (a) Main effect of condition for happiness ratings. (b-d) Main effect of group, condition, and interaction for surprise ratings. (e-g) Main effect of group, condition, and interaction for sadness ratings. (h-j) Main effect of group, condition, and interaction for anger ratings. (k-m) Main effect of group, condition, and interaction for disgust ratings. (n-p) Main effect of group, condition, and interaction for fear ratings. (r-s) Main effect of group and condition for valence ratings. (t-u) Main effect of group and condition for arousal ratings. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *p < 0.05, **p < 0.01, ***p < 0.001

2.4.4. fMRI results of the autobiographical memory task

Whole brain GLM results. The analysis of the main effect of task revealed a broad network of activations (p < 0.001, FWEc corrected with cluster-level extent threshold of p < 0.05 and cluster size of k = 274 voxels; Figure 15) including regions within the frontal, temporal, occipital, and parietal cortices, and all the regions selected for the ROI analyses. The obtained clusters and peaks of activation are presented in Table 3.

Table 3. Brain activations for the main effect of task (SAD+HAPPY). Significant p values are written in bold. The results were thresholded at voxel-wise height threshold of p < 0.001 (uncorrected) combined with a cluster-level extent-threshold of p < 0.05 and cluster size of k = 274 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
Main effect of AM recall (SAD+HAPPY)								
Lingual gyrus	L	7419	11.59	-1	-88	-1	**< 0.001**	**< 0.001**
Cuneus	R		9.50	16	-100	6		**< 0.001**
Middle occipital gyrus	L		9.31	-12	-102	4		**< 0.001**
Inferior orbitofrontal gyrus	L	29138	10.64	-46	22	-6	**< 0.001**	**< 0.001**
Middle temporal pole	R		10.40	50	10	-34		**< 0.001**
Inferior orbitofrontal gyrus	R		9.82	52	22	-4		**< 0.001**
Postcentral gyrus	L	274	7.75	-38	-16	38	**< 0.001**	**< 0.001**
Precentral gyrus	L		4.86	-46	-12	28		0.1
Postcentral gyrus	L		3.97	-58	-6	16		0.81
Precentral gyrus	R	650	6.64	42	-14	36	**< 0.001**	**< 0.001**
Precentral gyrus	R		6.49	44	0	44		**< 0.001**
Middle frontal gyrus	R		5.04	48	2	54		0.06
Supramarginal gyrus	R	398	6.00	64	-48	26	**< 0.001**	**0.002**
Angular gyrus	R		5.18	60	-56	26		**0.03**
Angular gyrus	R		4.51	54	-66	32		0.28

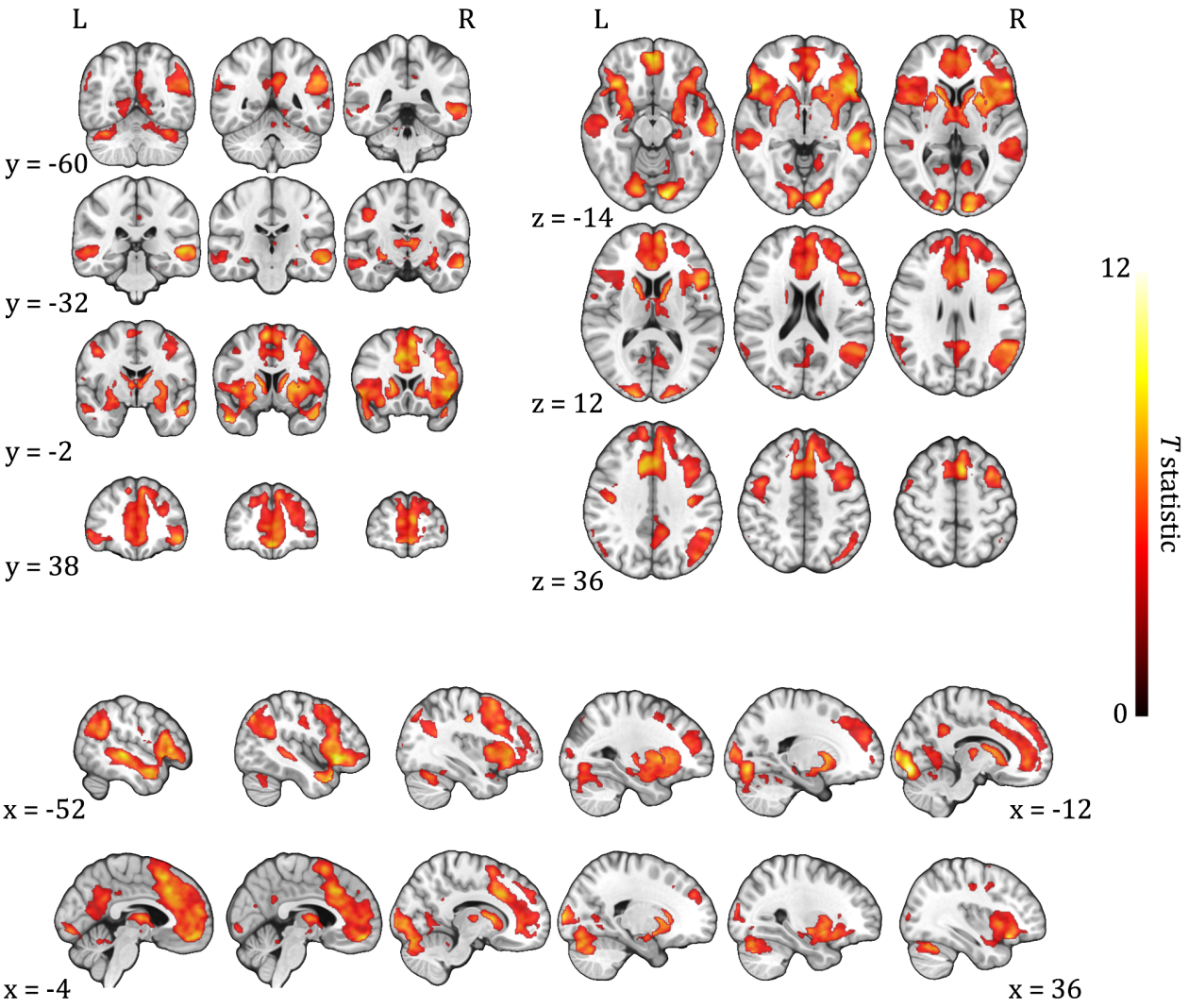

Figure 15. Whole-brain statistical parametric maps representing brain activation for the main effect of task (SAD+HAPPY). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 274 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

A paired t-test was used to identify regions activated by sad or happy AMs across all participants (SAD > HAPPY and HAPPY > SAD) and it revealed that sad AMs, as compared to happy AMs, were related to greater significant activations among multiple brain regions, including frontal and insular cortices ($p < 0.001$ FWEc corrected with cluster-level extent threshold of $p < 0.05$ and cluster size of k = 185 voxels; Figure 16 and Table 4). The comparison of happy AMs to sad ones did not reveal significant differences.

Table 4. Differences in brain activation between conditions for all participants (SAD > HAPPY and HAPPY > SAD contrasts). Significant *p* values are written in bold. The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 185 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
SAD > HAPPY								
Superior frontal gyrus	L	10360	6.49	-20	40	34	**< 0.001**	**< 0.001**
Middle cingulate cortex	L		6.31	-2	12	40		**0.001**
Inferior orbitofrontal gyrus	L		6.01	-50	18	-4		**0.002**
Supramarginal gyrus	L	828	6.48	-54	-52	28	**< 0.001**	**< 0.001**
Inferior parietal gyrus	L		5.94	-56	-52	38		**0.002**
Angular gyrus	L		5.41	-58	-58	32		**0.02**
Inferior frontal gyrus	R	1679	5.41	54	18	-4	**< 0.001**	**0.02**
Insular cortex	R		5.37	44	14	-6		**0.02**
Insular cortex	R		5.27	38	14	0		**0.02**
Cerebellum	L	305	5.25	-28	-70	-28	**0.002**	**0.03**
Cerebellum	L		5.20	-6	-78	-22		**0.03**
Cerebellum	R	303	4.57	20	-84	-28	**0.002**	0.23
Cerebellum	R		4.50	6	-80	-22		0.28
Cerebellum	R		4.26	34	-66	-26		0.5
Caudate	R	185	4.53	12	24	0	**0.02**	0.26
Striatum	R		4.43	2	16	-4		0.34
HAPPY > SAD								
No suprathreshold clusters								

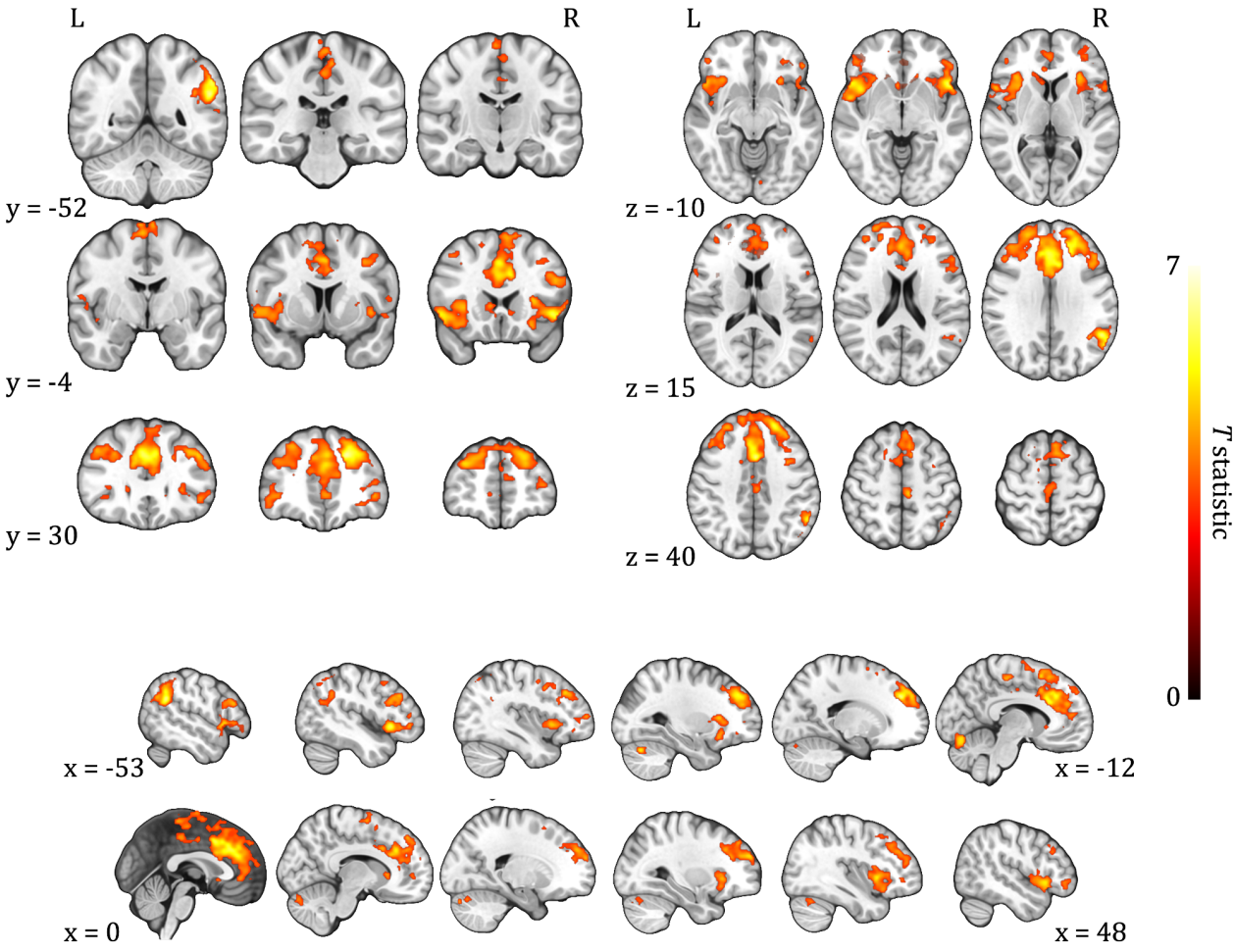

Figure 16. Differences in brain activation between conditions for all participants (SAD > HAPPY). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 185 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

The analysis of the main effect of group revealed no significant differences. The flexible factorial analysis of interaction between group and condition revealed no significant results.

An analysis for research question Q2a, investigating whether the MDD group differed significantly from the HC group in processing of happy memories (MDD > HC and HC > MDD), also revealed no significant results. Moreover, analysis for research question Q2b, to see whether the BPD group differed significantly in processing of happy memories from the HC group (BPD > HC and HC > BPD), revealed no significant results. An analysis for research question Q2c, investigating if MDD and BPD individuals process happy AMs differentially on the neural level (MDD > BPD and BPD > MDD), revealed no significant differences.

ROI results. An analysis for the hypotheses H4a and H4b, predicting that MDD and BPD groups would have higher activations in the amygdala, insula, ACC, occipital cortex, and

precuneus during sad AMs recall than the HC group (MDD > HC and BPD > HC), did not reveal any significant results. An analysis for the hypothesis H4c, predicting that the BPD group will have higher activation in the amygdala, insula, ACC, occipital cortex, and precuneus than the MDD group during sad AMs recall (BPD > MDD), did not reveal any significant results.

An analysis for the research question Q3a, investigating if sad and happy AMs differ from each other in terms of activation in the vmPFC and PCC (SAD > HAPPY and HAPPY > SAD), revealed that during sad recall PCC had significantly higher activation (T = 3.91, p at cluster level = 0.02, p at peak level = 0.02, FWE and SVC corrected). The activity of the vmPFC ROI did not show significant difference (T = 3.39, p at cluster level = 0.07, p at peak level = 0.07, FWE and SVC corrected). The comparison of happy to sad AMs did not show any significant results. A flexible factorial analysis for the research question Q3b, investigating whether sad and happy AMs differed between the clinical groups in terms of activation in the vmPFC and PCC, did not show any significant results.

Functional connectivity results. Hierarchical clustering procedure, performed on data taken from all participants, revealed four clusters. Cluster A included left PCC and left precuneus. Cluster B included left and right amygdalae and left and right hippocampi. Cluster C included right vmPFC, left and right AG, left and right insulae, and left ACC. Cluster D included left and right occipital cortices (clusters are summarized in Table 5).

Table 5. Summary of clusters revealed by hierarchical clustering procedure. ROIs - regions of interest; PCC - posterior cingulate cortex; vmPFC - ventromedial prefrontal cortex; AG - angular gyrus; ACC - anterior cingulate cortex.

Cluster name	ROIs
Cluster A	left PCC, left precuneus
Cluster B	left and right amygdalae, left and right hippocampi
Cluster C	right vmPFC, left and right AG, left and right insulae, left ACC
Cluster D	left and right occipital cortices

The analysis of the main effect of task revealed strong significant connections within all the clusters and between them (please see Table 6 and Figure 17 for detailed description).

Table 6. Functional connectivity results of the main effect of task. The results were FDR-corrected at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for comparisons between individual connections. As all p values were significant, they are not written in bold. L - left hemisphere; R - right hemisphere; PCC - posterior cingulate cortex; OCC - occipital cortex; ACC - anterior cingulate cortex; AG - angular gyrus; vmPFC - ventromedial prefrontal cortex.

Clusters and connections	Statistic	*p* uncorrected	*p* FDR-corrected
Main effect of recall (SAD+HAPPY)			
Within Cluster A	$F(1, 81) = 7594.41$	< 0.001	< 0.001
PCC L - Precuneus L	$T = 87.15$	< 0.001	< 0.001
Within Cluster D	$F(1, 81) = 342.09$	< 0.001	< 0.001
OCC L - OCC R	$T = 18.50$	< 0.001	< 0.001
Within Cluster B	$F(3, 79) = 308.75$	< 0.001	< 0.001
Amygdala R - Hippocampus R	$T = 27.35$	< 0.001	< 0.001
Amygdala L - Hippocampus L	$T = 27.11$	< 0.001	< 0.001
Amygdala L - Amygdala R	$T = 18.85$	< 0.001	< 0.001
Amygdala L - Hippocampus R	$T = 18.67$	< 0.001	< 0.001
Hippocampus L - Hippocampus R	$T = 14.94$	< 0.001	< 0.001
Hippocampus L - Amygdala R	$T = 13.18$	< 0.001	< 0.001
Within Cluster C	$F(3, 79) = 148.92$	< 0.001	< 0.001
Insula L - Insula R	$T = 16.52$	< 0.001	< 0.001
Insula L - ACC L	$T = 16.06$	< 0.001	< 0.001
ACC L - Insula R	$T = 11.95$	< 0.001	< 0.001
AG L - AG R	$T = 11.17$	< 0.001	< 0.001
AG L - Insula R	$T = 7.64$	< 0.001	< 0.001
Insula L - AG L	$T = 7.13$	< 0.001	< 0.001
ACC L - AG R	$T = 6.99$	< 0.001	< 0.001
ACC L - AG L	$T = 6.64$	< 0.001	< 0.001
Insula L - AG R	$T = 5.96$	< 0.001	< 0.001
Insula R - vmPFC R	$T = 5.75$	< 0.001	< 0.001
Insula R - AG R	$T = 5.66$	< 0.001	< 0.001
AG L - vmPFC R	$T = 4.58$	< 0.001	< 0.001
ACC L - vmPFC R	$T = 3.88$	< 0.001	< 0.001
Insula L - vmPFC R	$T = 2.81$	0.01	0.01
Between Clusters A and C	$F(3, 79) = 104.93$	< 0.001	< 0.001
PCC L - vmPFC R	$T = 14.86$	< 0.001	< 0.001
Precuneus L - vmPFC R	$T = 13.31$	< 0.001	< 0.001
Precuneus L - AG L	$T = 11.28$	< 0.001	< 0.001
PCC L - AG L	$T = 11.25$	< 0.001	< 0.001
Precuneus L - AG R	$T = 7.53$	< 0.001	< 0.001
PCC L - AG R	$T = 7.11$	< 0.001	< 0.001

Clusters and connections	Statistic	*p* uncorrected	*p* FDR-corrected
PCC L - Insula R	*T* = 6.46	< 0.001	< 0.001
Precuneus L - Insula R	*T* = 6.03	< 0.001	< 0.001
PCC L - Insula L	*T* = 4.74	< 0.001	< 0.001
PCC L - ACC L	*T* = 4.72	< 0.001	< 0.001
Precuneus L - Insula L	*T* = 4.35	< 0.001	< 0.001
Precuneus L - ACC L	*T* = 4.29	< 0.001	< 0.001
Between Clusters B and C	*F*(3, 79) = 72.24	< 0.001	< 0.001
Amygdala L - vmPFC R	*T* = 9.95	< 0.001	< 0.001
Hippocampus R - vmPFC R	*T* = 9.87	< 0.001	< 0.001
Hippocampus L - vmPFC R	*T* = 9.41	< 0.001	< 0.001
Amygdala R - Insula R	*T* = 8.26	< 0.001	< 0.001
Amygdala L - ACC L	*T* = 8.04	< 0.001	< 0.001
Amygdala L - Insula R	*T* = 7.02	< 0.001	< 0.001
Amygdala R - vmPFC R	*T* = 6.78	< 0.001	< 0.001
Amygdala L - Insula L	*T* = 6.52	< 0.001	< 0.001
Hippocampus L - AG L	*T* = 6.39	< 0.001	< 0.001
Hippocampus R - Insula R	*T* = 6.35	< 0.001	< 0.001
Amygdala R - ACC L	*T* = 6.02	< 0.001	< 0.001
Hippocampus L - Insula R	*T* = 5.72	< 0.001	< 0.001
Hippocampus R - AG L	*T* = 4.75	< 0.001	< 0.001
Amygdala L - AG L	*T* = 4.69	< 0.001	< 0.001
Amygdala R - Insula L	*T* = 4.25	< 0.001	< 0.001
Amygdala R - AG L	*T* = 4.08	< 0.001	< 0.001
Hippocampus L - Insula L	*T* = 4.06	< 0.001	< 0.001
Hippocampus R - ACC L	*T* = 3.75	< 0.001	< 0.001
Hippocampus R - Insula L	*T* = 3.11	0.003	0.003
Hippocampus L - ACC L	*T* = 3.05	0.003	0.003
Between Clusters A and D	F(2, 80) = 36.96	< 0.001	< 0.001
PCC L - OCC R	*T* = 8.52	< 0.001	< 0.001
Precuneus L - OCC R	*T* = 8.18	< 0.001	< 0.001
PCC L - OCC L	*T* = 6.56	< 0.001	< 0.001
Precuneus L - OCC L	*T* = 6.32	< 0.001	< 0.001
Between Clusters A and B	*F*(3, 79) = 34.18	< 0.001	< 0.001
Precuneus L - Hippocampus R	*T* = 1.13	< 0.001	< 0.001
PCC L - Hippocampus R	*T* = 1.06	< 0.001	< 0.001
PCC L - Hippocampus L	*T* = 9.21	< 0.001	< 0.001
Precuneus L - Hippocampus L	*T* = 8.62	< 0.001	< 0.001
PCC L - Amygdala L	*T* = 6.95	< 0.001	< 0.001
Precuneus L - Amygdala L	*T* = 6.85	< 0.001	< 0.001
Precuneus L - Amygdala R	*T* = 5.08	< 0.001	< 0.001
PCC L - Amygdala R	*T* = 5	< 0.001	< 0.001
Between Clusters D and C	*F*(3, 79) = 33.05	< 0.001	< 0.001

Clusters and connections	Statistic	*p* uncorrected	*p* FDR-corrected
OCC R - vmPFC R	*T* = 9.33	< 0.001	< 0.001
OCC L - Insula R	*T* = 6.39	< 0.001	< 0.001
OCC L - vmPFC R	*T* = 5.77	< 0.001	< 0.001
OCC R - AG L	*T* = 5.72	< 0.001	< 0.001
OCC L - AG L	*T* = 5.20	< 0.001	< 0.001
OCC R - Insula R	*T* = 4.91	< 0.001	< 0.001
OCC L - Insula L	*T* = 4.41	< 0.001	< 0.001
OCC R - Insula L	*T* = 4.35	< 0.001	< 0.001
OCC L - ACC L	*T* = 3.40	0.001	0.001
OCC R - ACC L	*T* = 2.92	0.005	0.006
OCC R - AG R	*T* = 2.34	0.02	0.02
Between Clusters D and B	*F*(3, 79) = 9.71	< 0.001	< 0.001
OCC L - Amygdala L	*T* = 4.74	< 0.001	< 0.001
OCC R - Hippocampus L	*T* = 4.20	< 0.001	< 0.001
OCC L - Hippocampus R	*T* = 3.84	< 0.001	< 0.001
OCC L - Hippocampus L	*T* = 3.35	0.001	0.001
OCC R - Amygdala L	*T* = 3.35	0.001	0.002
OCC R - Hippocampus R	*T* = 2.77	0.01	0.01
OCC L - Amygdala R	*T* = 2.43	0.02	0.02
OCC R - Amygdala R	*T* = 2.03	0.05	0.05

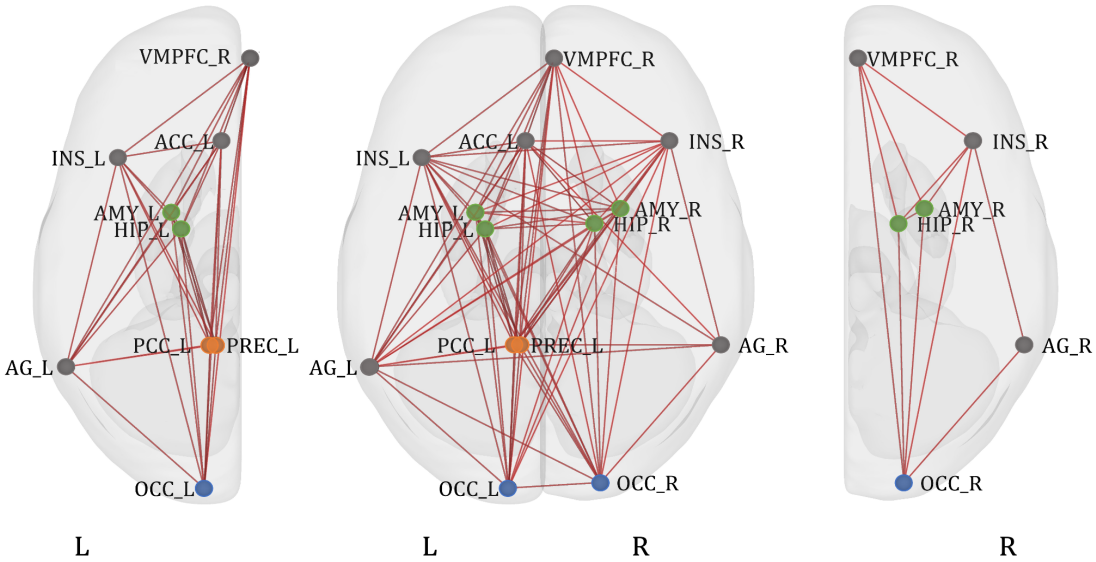

Figure 17. ROI-to-ROI functional connectivity of the main effect of task (SAD+HAPPY). Orange color represents ROIs of the Cluster A, green color represents Cluster B, grey color represents cluster C, blue color represents Cluster D. The results were FDR-corrected at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for comparisons between individual connections. L - left hemisphere; R - right hemisphere; VMPFC - ventromedial prefrontal cortex; INS - insular cortex; ACC - anterior cingulate cortex; AMY - amygdala; HIP - hippocampus; AG - angular gyrus; PCC - posterior cingulate cortex; PREC - precuneus; OCC - occipital cortex.

An analysis of possible differences between sad and happy AMs recalls for all participants taken together (Q4) revealed 3 groups of connections that had significantly greater functional connectivity during sad AMs (SAD > HAPPY). Within the Cluster C ($F(3, 79) = 4.40$, p uncorrected = 0.01, p FDR-corrected = 0.03) there were 5 connections between all its ROIs except for the left AG. Within the Cluster B ($F(3, 79) = 4.31$, p uncorrected = 0.01, p FDR-corrected = 0.03) there was one connection between the right amygdala and right hippocampus. The third group of connections ($F(3, 79) = 4.26$, p uncorrected = 0.01, p FDR-corrected = 0.03) consisted of 6 connections between Clusters A and B. Detailed description of these results is reported in Table 7 and presented on Figure 18. No clusters showed significantly increased connectivity for the happy memories.

Table 7. Functional connectivity results of the comparison of sad and happy AMs recall (SAD > HAPPY) for all participants. Significant p values are written in bold. The analysis was FDR-corrected at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for comparisons between individual connections. L - left hemisphere; R - right hemisphere; vmPFC - ventro-medial prefrontal cortex; AG - angular gyrus; ACC - anterior cingulate cortex; PCC - posterior cingulate cortex.

Clusters and connections	Statistic (df)	*p* uncorrected	*p* FDR-corrected
SAD > HAPPY			
Within Cluster C	$F(3, 79) = 4.40$	**0.01**	**0.03**
Insula L - vmPFC R	$T = 3.31$	**0.01**	**0.02**
AG R - vmPFC R	$T = 2.47$	**0.02**	0.08
AG R - Insula L	$T = -2.42$	**0.02**	0.12
Insula R - ACC L	$T = 2.36$	**0.02**	0.19
ACC L - vmPFC R	$T = 2.10$	**0.04**	0.19
Within Cluster B	$F(3, 79) = 4.31$	**0.01**	**0.03**
Amygdala R - Hippocampus R	$T = 3.62$	**0.001**	**0.01**
Between Clusters A and B	$F(3, 79) = 4.26$	**0.01**	**0.03**
Precuneus L - Amygdala R	$T = 2.79$	**0.01**	**0.04**
Precuneus L - Hippocamp us R	$T = 2.71$	**0.01**	**0.04**
Precuneus L - Hippocampus L	$T = 2.66$	**0.01**	**0.04**
PCC L - Hippocampus R	$T = 2.66$	**0.01**	0.1
PCC - Hippocampus L	$T = 2.43$	**0.02**	0.1
PCC L - Amygdala R	$T = 2.31$	**0.02**	0.1

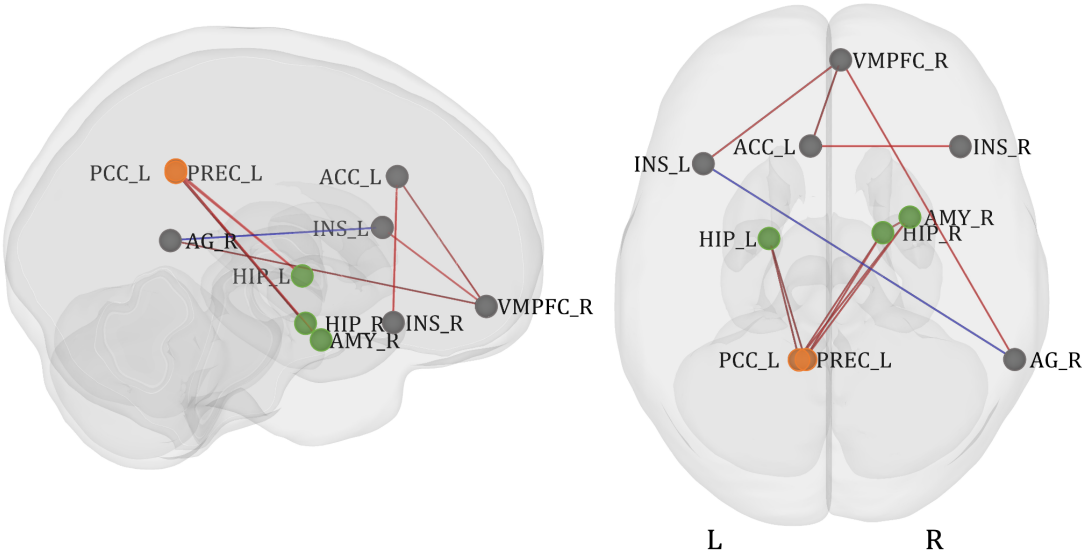

Figure 18. ROI-to-ROI functional connectivity of the comparison of sad and happy AMs recall (SAD > HAPPY) for all participants. Red color indicates increased connectivity, whereas blue color indicates decreased connectivity. Orange color represents ROIs from the Cluster A, green color represents Cluster B, grey color represents Cluster C. The results were FDR-corrected at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for comparisons between individual connections. L - left hemisphere; R - right hemisphere; PCC - posterior cingulate cortex; PREC - precuneus; ACC - anterior cingulate cortex; AG - angular gyrus; INS - insular cortex; HIP - hippocampus; VMPFC - ventromedial prefrontal cortex; AMY - amygdala.

Two analyses were performed to explore whether there were differences between and within the groups for sad and happy AMs recall (Q5). First, the main effect of group (SAD + HAPPY AMs) revealed one significant group of connections ($F(4, 156) = 3.97$, p uncorrected = 0.004, p FDR-corrected = 0.04; see Figure 19a) comprised of two connections between Clusters A and D. The connection between the left PCC and right occipital cortex was not statistically significant ($F(2, 79) = 4.75$, p uncorrected = 0.01, p FDR-corrected = 0.1). The connection between the left precuneus and right occipital cortex was an insignificant result ($F(2, 79) = 5.61$, p uncorrected = 0.01, p FDR-corrected = 0.07). Because the F test for the group of connections was significant, post hoc comparisons were performed between the participant groups. They did not reveal any significant results. However, when MDD and BPD groups were taken together and compared to the HC group (MDD + BPD > HC), the analysis revealed the same group of connections as significant ($F(2, 78) = 6.04$, p uncorrected = 0.004, p FDR-corrected = 0.04), with the same two connections (Figure 19b). The clinical groups taken together had significantly greater connectivity between the right occipital cortex and left precuneus ($T = 3.12$, p

uncorrected = 0.002, *p* FDR-corrected = 0.03). The connection between the right occipital cortex and left PCC was statistically insignificant (*T* = 2.83, *p* uncorrected = 0.01, *p* FDR-corrected = 0.08).

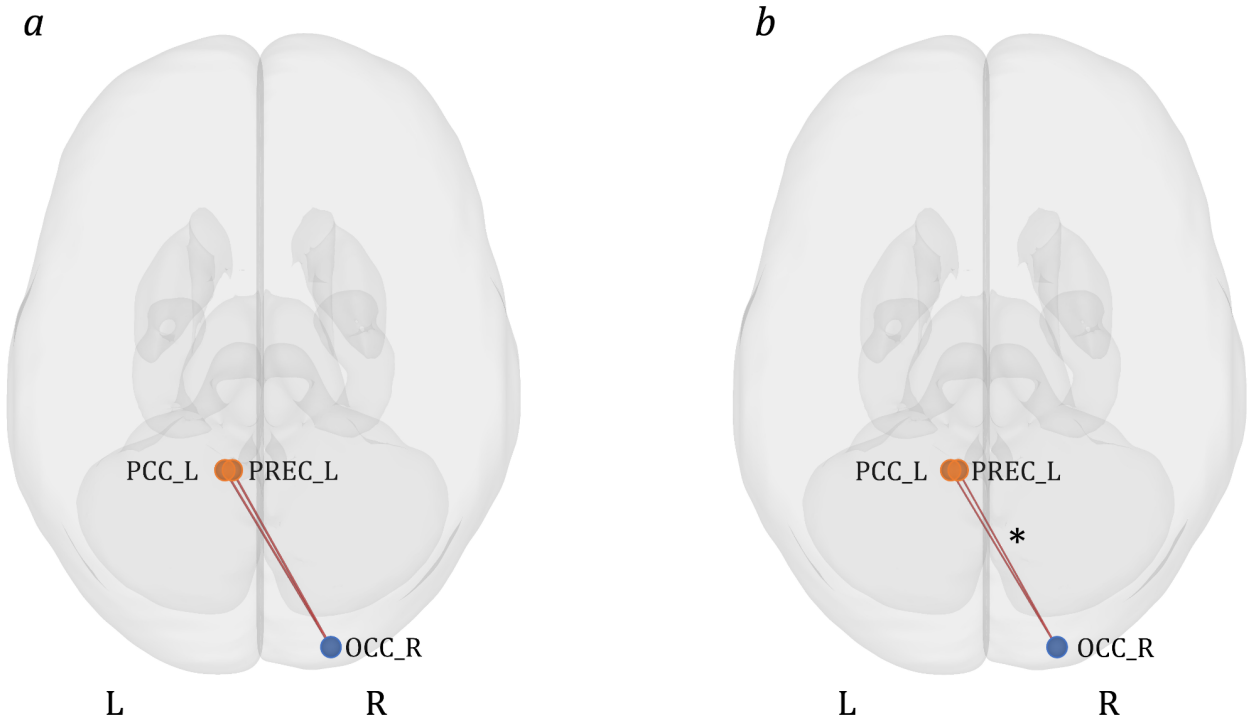

Figure 19. ROI-to-ROI functional connectivity of the main effect of group and comparison of clinical groups to healthy control. (a) Results of the main effect of group. (b) Results of the comparison of clinical groups taken together to the healthy control group (MDD+BPD > HC). Orange color represents ROIs from the Cluster A, blue color represents Cluster D. The results were FDR-corrected at $p < 0.05$ for the cluster-level threshold (two-sided) together with an uncorrected $p < 0.05$ connection-level threshold for comparisons between individual connections. L - left hemisphere; R - right hemisphere; PCC - posterior parietal cortex; PREC - precuneus; OCC - occipital cortex. *$p < 0.05$

The interaction analysis for research question Q5 did not show any significant results. Two 3x1 ANOVA models looking for group effects for sad and happy AMs recall separately did not reveal any significant results.

2.4.5. Behavioral ratings during the emotion regulation task

Comparison of view $VIEW_{SAD\_REAP}$ and $VIEW_{SAD\_MIND}$ conditions revealed that $VIEW_{SAD\_MIND}$ had lower emotions ratings ($T = -7.01$, $p < 0.001$). This means that the emotional

state was rated as sadder after watching sad pictures in MA run than in CR run. There were no significant differences between the conditions for success ratings. I decided to keep ratings of these two conditions separate for further analyses (and not average their ratings as done with the autobiographical task).

Comparison of $VIEW_{NEU\_REAP}$ and $VIEW_{NEU\_MIND}$ conditions revealed that $VIEW_{NEU\_MIND}$ had lower emotions ratings (T = -3.55, p < 0.001). This means that the emotional state after watching neutral pictures was rated as sadder (or less neutral) in MA run than in CR run. Also, in this case there were no significant differences for success ratings. These ratings were kept as separate conditions as well.

Question about emotional state. An analysis testing hypothesis H5a, that the MDD group will rate their emotional state as sadder after ER in general than the HC group, revealed no significant difference between the groups (W = 1925, p = 0.3). An analysis to test hypothesis H5b, that the BPD group will rate their emotional state as sadder after ER in general than the HC, also did not reveal any significant difference (W = 1078, p = 0.16). An analysis to answer research question Q6a - if CR and MA strategies will differ in emotional state ratings - showed that the emotional state across all participants was less sad after CR than MA (W = 6237, p < 0.001; Figure 20a). Analyses for questions Q7a and Q7b - if CR and MA differed in emotional state ratings within MDD and BPD groups - showed that emotional state in both groups was less sad after CR than MA (MDD: U = 435, p < 0.001; BPD: U = 171, p < 0.001; Figure 20b).

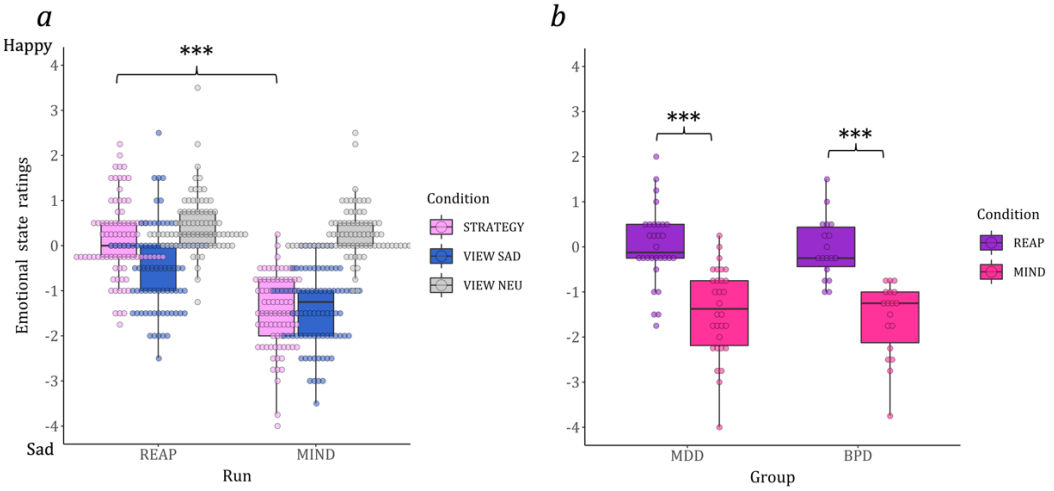

Figure 20. Results of research questions regarding emotional state after regulation. Significant results of the analyses to answer research questions (a) Q6a and (b) Q7 are marked. The rating scale was changed from 1-9 points to -4-4 points for better visualization purposes. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. ***$p < 0.001$.

Remaining analyses revealed a significant main effect of run ($F(1, 395) = 222.86$, $p < 0.001$, $\eta_p^2 = 0.36$), a significant main effect of condition ($F(2, 395) = 175.91$, $p < 0.001$, $\eta_p^2 = 0.47$), a significant interaction between run and condition ($F(2, 395) = 43.61$, $p < 0.001$, $\eta_p^2 = 0.18$), and a significant interaction between group, run, and condition ($F(4, 395) = 3.1$, $p < 0.05$, $\eta_p^2 = 0.03$). There was no significant main effect of group ($F(2, 79) = 0.83$, $p = 0.44$, $\eta_p^2 = 0.02$), no significant interaction between group and run ($F(2, 395) = 1.9$, $p = 0.2$, $\eta_p^2 = 0.01$), and no significant interaction between group and condition ($F(4, 395) = 1.21$, $p = 0.31$, $\eta_p^2 = 0.03$). Post hoc tests of the significant main effects and interactions are presented in Table 8 and Figure 21.

Table 8. Behavioral results of the emotional state ratings. Significant *p* values are written in bold. REAP – run with cognitive reappraisal; MIND – run with mindful acceptance; STRATEGY – regulation strategy condition; $VIEW_{SAD}$ – viewing sad pictures; $VIEW_{NEU}$ – viewing neutral pictures.

Post hoc comparisons	Statistic	*p*	Direction of effect
Main effect of run			
REAP VS MIND	$T = 14.24$	**< 0.001**	REAP > MIND
Main effect of condition			
STRATEGY VS $VIEW_{SAD}$	$T = 2.85$	**0.005**	STRATEGY > $VIEW_{SAD}$
STRATEGY VS $VIEW_{NEU}$	$T = -13.95$	**< 0.001**	STRATEGY < $VIEW_{NEU}$

Post hoc comparisons	Statistic	*p*	Direction of effect
$VIEW_{SAD}$ VS $VIEW_{NEU}$	*T* = -16.8	**< 0.001**	$VIEW_{SAD}$ < $VIEW_{NEU}$
Run x Condition			
REAP STRATEGY VS REAP $VIEW_{SAD}$	*U* = 232.5	**< 0.001**	REAP STRATEGY > REAP $VIEW_{SAD}$
REAP STRATEGY VS REAP $VIEW_{NEU}$	*U* = 901	**0.03**	REAP STRATEGY < REAP $VIEW_{NEU}$
REAP $VIEW_{SAD}$ VS REAP $VIEW_{NEU}$	*U* = 131.5	**< 0.001**	REAP $VIEW_{SAD}$ < REAP $VIEW_{NEU}$
MIND STRATEGY VS MIND $VIEW_{SAD}$	*U* = 183	0.36	
MIND STRATEGY VS MIND $VIEW_{NEU}$	*U* = 5.5	**< 0.001**	MIND STRATEGY < MIND $VIEW_{NEU}$
MIND $VIEW_{SAD}$ VS MIND $VIEW_{NEU}$	*U* = 17.5	**< 0.001**	MIND $VIEW_{SAD}$ < MIND $VIEW_{NEU}$
REAP STRATEGY VS MIND STRATEGY	*W* = 623	**< 0.001**	REAP STRATEGY > MIND STRATEGY
REAP $VIEW_{SAD}$ VS MIND $VIEW_{SAD}$	*W* = 507.5	**< 0.001**	REAP $VIEW_{SAD}$ > MIND $VIEW_{SAD}$
REAP $VIEW_{NEU}$ VS MIND $VIEW_{NEU}$	*W* = 413	**0.03**	REAP $VIEW_{NEU}$ < MIND $VIEW_{NEU}$
Group x Run x Condition			
Within MDD			
REAP STRATEGY VS REAP $VIEW_{SAD}$	*U* = 526	1	
REAP STRATEGY VS REAP $VIEW_{NEU}$	*U* = 69.5	0.12	
REAP $VIEW_{SAD}$ VS REAP $VIEW_{NEU}$	*U* = 23	**0.01**	REAP $VIEW_{SAD}$ < REAP $VIEW_{NEU}$
MIND STRATEGY VS MIND $VIEW_{SAD}$	*U* = 217	1	
MIND STRATEGY VS MIND $VIEW_{NEU}$	*U* = 1	**< 0.001**	MIND STRATEGY < MIND $VIEW_{NEU}$
MIND $VIEW_{SAD}$ VS MIND $VIEW_{NEU}$	*U* = 4.5	**< 0.001**	MIND $VIEW_{SAD}$ < MIND $VIEW_{NEU}$
REAP STRATEGY VS MIND STRATEGY	*U* = 435	**< 0.001**	REAP STRATEGY > MIND STRATEGY
REAP $VIEW_{SAD}$ VS MIND $VIEW_{SAD}$	*U* = 378	**< 0.001**	REAP $VIEW_{SAD}$ > MIND $VIEW_{SAD}$
REAP $VIEW_{NEU}$ VS MIND $VIEW_{NEU}$	*U* = 175.5	1	
Within BPD			
REAP STRATEGY VS REAP $VIEW_{SAD}$	*U* = 188	1	
REAP STRATEGY VS REAP $VIEW_{NEU}$	*U* = 33.5	1	
REAP $VIEW_{SAD}$ VS REAP $VIEW_{NEU}$	*U* = 24.5	0.4	
MIND STRATEGY VS MIND $VIEW_{SAD}$	*U* = 44	1	
MIND STRATEGY VS MIND $VIEW_{NEU}$	*U* = 107	**0.01**	MIND STRATEGY < MIND $VIEW_{NEU}$
MIND $VIEW_{SAD}$ VS MIND $VIEW_{NEU}$	*U* = 36.5	**0.02**	MIND $VIEW_{SAD}$ < MIND $VIEW_{NEU}$
REAP STRATEGY VS MIND STRATEGY	*U* = 171	**0.01**	REAP STRATEGY > MIND STRATEGY
REAP $VIEW_{SAD}$ VS MIND $VIEW_{SAD}$	*U* = 80	0.5	
REAP $VIEW_{NEU}$ VS MIND $VIEW_{NEU}$	*U* = 81	1	
Within HC			
REAP STRATEGY VS REAP $VIEW_{SAD}$	*U* = 482.5	**0.001**	REAP STRATEGY > REAP $VIEW_{SAD}$
REAP STRATEGY VS REAP $VIEW_{NEU}$	*U* = 237	1	
REAP $VIEW_{SAD}$ VS REAP $VIEW_{NEU}$	*U* = 2.5	**< 0.001**	REAP $VIEW_{SAD}$ < REAP $VIEW_{NEU}$
MIND STRATEGY VS MIND $VIEW_{SAD}$	*U* = 178.5	1	
MIND STRATEGY VS MIND $VIEW_{NEU}$	*U* = 2	**< 0.001**	MIND STRATEGY < MIND $VIEW_{NEU}$
MIND $VIEW_{SAD}$ VS MIND $VIEW_{NEU}$	*U* = 1	**< 0.001**	MIND $VIEW_{SAD}$ < MIND $VIEW_{NEU}$
REAP STRATEGY VS MIND STRATEGY	*U* = 595	**< 0.001**	REAP STRATEGY > MIND STRATEGY
REAP $VIEW_{SAD}$ VS MIND $VIEW_{SAD}$	*U* = 315	0.07	

Post hoc comparisons	Statistic	*p*	Direction of effect
REAP $VIEW_{NEU}$ VS MIND $VIEW_{NEU}$	$U = 246$	1	
Between MDD and HC			
MDD REAP STRATEGY VS HC REAP STRATEGY	$W = 398.5$	1	
MDD REAP $VIEW_{SAD}$ VS HC REAP $VIEW_{SAD}$	$W = 624$	1	
MDD REAP $VIEW_{NEU}$ VS HC REAP $VIEW_{NEU}$	$W = 592.5$	1	
MDD MIND STRATEGY VS HC MIND STRATEGY	$W = 517$	1	
MDD MIND $VIEW_{SAD}$ VS HC MIND $VIEW_{SAD}$	$W = 339$	0.53	
MDD MIND $VIEW_{NEU}$ VS HC MIND $VIEW_{NEU}$	$W = 500.5$	1	
Between BPD and HC			
BPD REAP STRATEGY VS HC REAP STRATEGY	$W = 216.5$	1	
BPD REAP $VIEW_{SAD}$ VS HC REAP $VIEW_{SAD}$	$W = 373$	1	
BPD REAP $VIEW_{NEU}$ VS HC REAP $VIEW_{NEU}$	$W = 227.5$	1	
BPD MIND STRATEGY VS HC MIND STRATEGY	$W = 270$	1	
BPD MIND $VIEW_{SAD}$ VS HC MIND $VIEW_{SAD}$	$W = 269$	1	
BPD MIND $VIEW_{NEU}$ VS HC MIND $VIEW_{NEU}$	$W = 173$	0.22	
Between MDD and BPD			
MDD REAP STRATEGY VS BPD REAP STRATEGY	$W = 288.5$	1	
MDD REAP $VIEW_{SAD}$ VS BPD REAP $VIEW_{SAD}$	$W = 269.5$	1	
MDD REAP $VIEW_{NEU}$ VS BPD REAP $VIEW_{NEU}$	$W = 359$	1	
MDD MIND STRATEGY VS BPD MIND STRATEGY	$W = 308.5$	1	
MDD MIND $VIEW_{SAD}$ VS BPD MIND $VIEW_{SAD}$	$W = 210.5$	1	
MDD MIND $VIEW_{NEU}$ VS BPD MIND $VIEW_{NEU}$	$W = 354.5$	1	

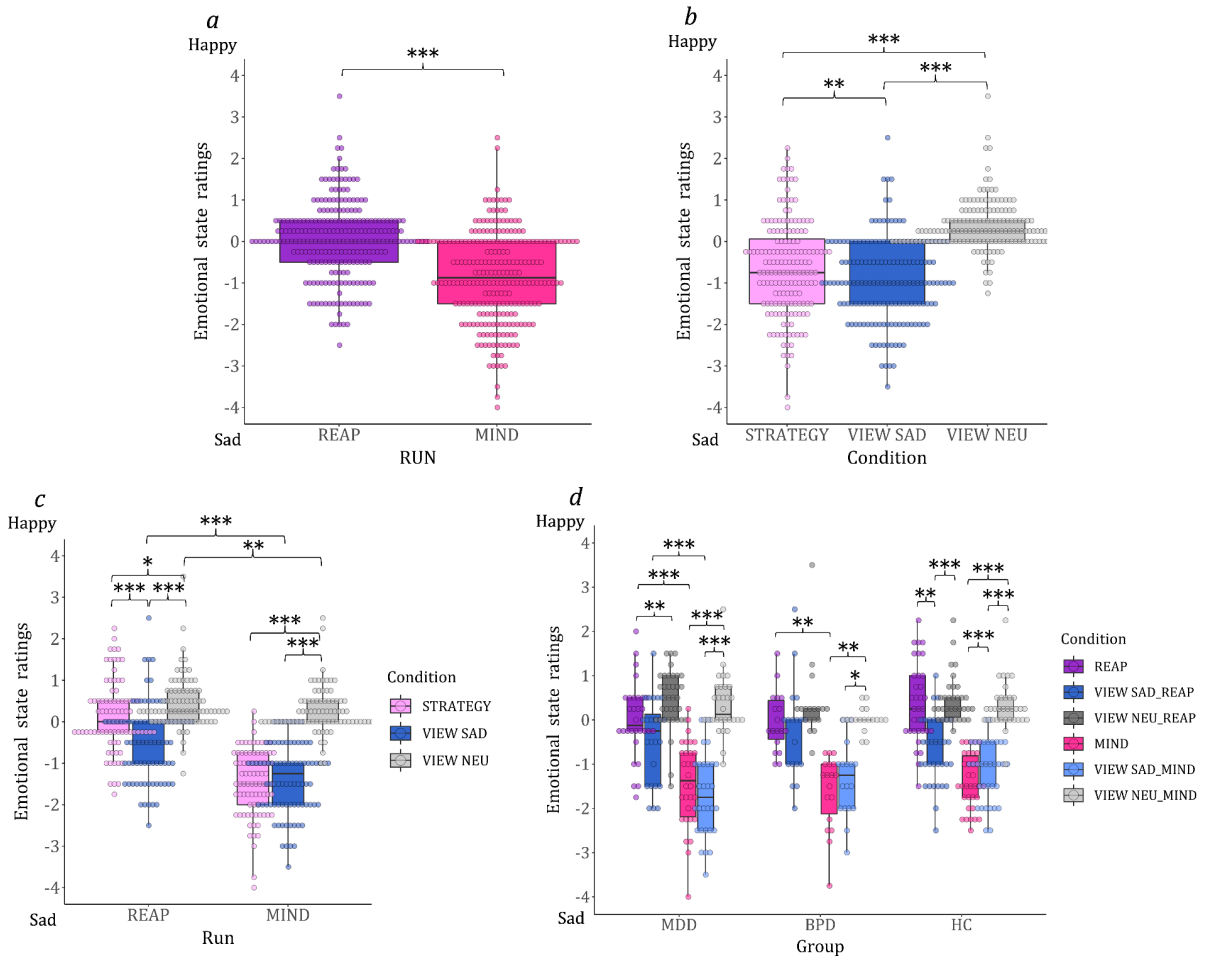

Figure 21. Behavioral results of the emotional state ratings. (a) Main effect of run. (b) Main effect of condition. (c) Interaction between run and condition. (d) Interaction between group, run, and condition. The rating scale was changed from 1-9 points to -4-4 points for better visualization purposes. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Question about success in following ER instructions. An analysis to answer research question Q6b - if CR and MA strategies would differ in ratings of success in implementing regulation instructions - showed that participants rated themselves as more successful in following MA instructions than CR ($W = 2062.5$, $p < 0.001$; Figure 22b). The analyses to answer questions Q7A and Q7b - if there were differences between the strategies in MDD and in BPD groups for success ratings - showed that in both groups the ratings were lower for the CR condition than MA (MDD: $U = 50$, $p = 0.001$; BPD: $U = 11$, $p = 0.01$; Figure 22b).

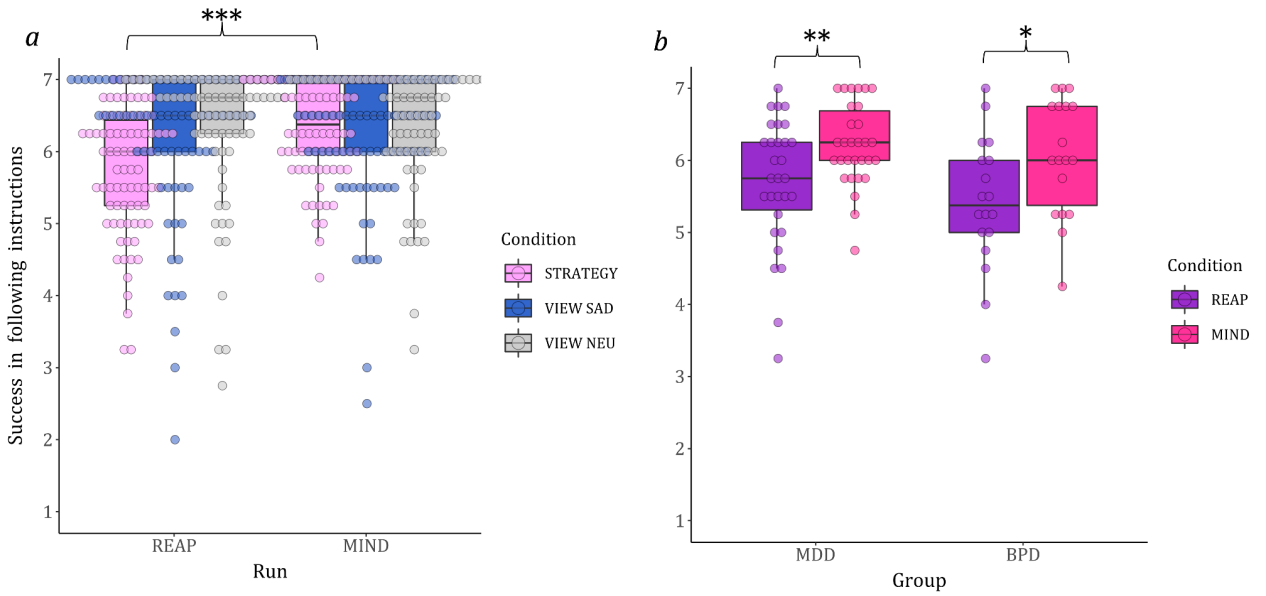

Figure 22. Results of research questions analyses regarding success in following regulation instructions. Significant results of the analyses to answer research questions Q6b and Q7 are marked. The rating scale was changed from 1-9 points to -4-4 points for better visualization purposes. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The remaining analyses revealed a significant main effect of group ($F(2, 79) = 7.11$, $p = 0.001$, $\eta_p^2 = 0.15$), a significant main effect of run ($F(1, 395) = 9.85$, $p = 0.002$, $\eta_p^2 = 0.02$), a significant main effect of condition ($F(2, 395) = 32.74$, $p < 0.001$, $\eta_p^2 = 0.14$), and a significant interaction between run and condition ($F(2, 395) = 18.05$, $p < 0.001$, $\eta_p^2 = 0.08$). There was no significant interaction between group and run ($F(2, 395) = 1.55$, $p = 0.21$, $\eta_p^2 = 0.01$), between group and condition ($F(4, 395) = 0.19$, $p = 0.9$, $\eta_p^2 = 0.002$), or between group, run, and condition ($F(4, 395) = 1.03$, $p = 0.4$, $\eta_p^2 = 0.01$). Post hoc tests of the significant main effects and interaction are presented in Table 9 and Figure 23.

Table 9. Behavioral results of the success in following regulation instructions. Significant *p* values are written in bold. REAP – run with cognitive reappraisal; MIND – run with mindful acceptance; STRATEGY – regulation strategy condition; $VIEW_{SAD}$ – viewing sad pictures; $VIEW_{NEU}$ – viewing neutral pictures.

Post hoc comparisons	Statistic	*p*	Direction of effect
Main effect of group			
MDD VS HC	T = -2.751	**0.01**	MDD < HC
BPD VS HC	T = -3.468	**0.003**	BPD < HC
MDD VS BPD	T = 1.08	0.28	
Main effect of run			
REAP VS MIND	T = -3.15	**0.002**	REAP < MIND
Main effect of condition			
STRATEGY VS $VIEW_{SAD}$	T = -4.5	**< 0.001**	STRATEGY < $VIEW_{SAD}$
STRATEGY VS $VIEW_{NEU}$	T = -7.74	**< 0.001**	STRATEGY < $VIEW_{NEU}$
$VIEW_{SAD}$ VS $VIEW_{NEU}$	T = -3.25	**0.001**	$VIEW_{SAD}$ < $VIEW_{NEU}$
Run x Condition			
REAP STRATEGY VS REAP $VIEW_{SAD}$	U = 493.4	**< 0.001**	REAP STRATEGY < REAP $VIEW_{SAD}$
REAP STRATEGY VS REAP $VIEW_{NEU}$	U = 242.5	**< 0.001**	REAP STRATEGY < REAP $VIEW_{NEU}$
REAP $VIEW_{SAD}$ VS REAP $VIEW_{NEU}$	U = 591	0.35	
MIND STRATEGY VS MIND $VIEW_{SAD}$	U = 995.5	0.83	
MIND STRATEGY VS MIND $VIEW_{NEU}$	U = 443	0.29	
MIND $VIEW_{SAD}$ VS MIND $VIEW_{NEU}$	U = 541	0.09	
REAP STRATEGY VS MIND STRATEGY	W = 206.5	**< 0.001**	
REAP $VIEW_{SAD}$ VS MIND $VIEW_{SAD}$	W = 359.5	0.84	
REAP $VIEW_{NEU}$ VS MIND $VIEW_{NEU}$	W = 324	0.84	

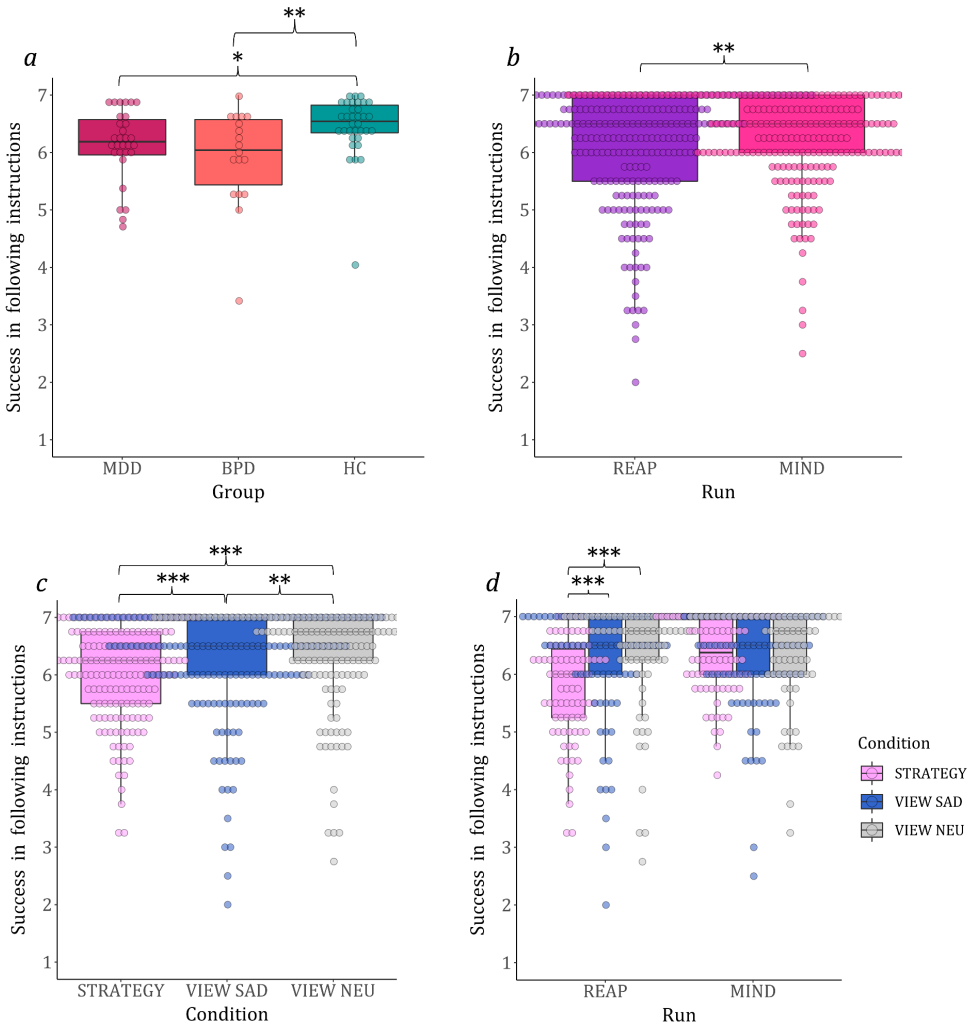

Figure 23. Behavioral results of the success in following task instructions. (a) Main effect of group. (b) Main effect of condition. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.4.6. fMRI results of the emotion regulation task

Whole brain GLM results. The analysis of the main effect of emotion regulation (REAP+MIND > 2x$VIEW_{SAD}$) revealed significant activation across multiple regions ($p < 0.001$, FWEc corrected with cluster-level extent threshold of $p < 0.05$ and cluster size of k = 113 voxels), including supplementary motor cortex, gyri of the prefrontal cortex, inferior occipital gyrus, medial cingulate cortex, insula, thalamus, and precuneus. The obtained results are presented in Table 10 and Figure 24.

Table 10. Brain activations for the main effect of emotion regulation. Significant *p* values are written in bold. The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < .005$ and cluster size of k = 113 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
Main effect of ER (REAP+MIND > 2xVIEW$_{SAD}$)								
Supplementary motor area	L	8237	80.86	-6	12	52	**< 0.001**	**< 0.001**
Supplementary motor area	L		74.86	-4	6	64		**< 0.001**
Supplementary motor area	L		69.83	0	12	60		**< 0.001**
Cerebellum	R	14436	72.51	38	-68	-24	**< 0.001**	**< 0.001**
Inferior occipital gyrus	L		62.28	-44	-76	-6		**< 0.001**
Inferior occipital gyrus	L		56.6	-36	-82	-6		**< 0.001**
Inferior frontal gyrus	R	1268	39.36	56	28	0	**< 0.001**	**0.001**
Insula	R		34.79	44	22	-6		**0.01**
Inferior frontal gyrus	R		32.29	56	28	10		**0.01**
Middle frontal gyrus	R	269	35.36	50	16	48	**< 0.001**	**0.01**
Precentral gyrus	R		25.56	40	2	42		0.12
Caudate	R	168	31.95	18	14	10	**0.01**	**0.02**
Caudate	R		19.81	14	-2	22		0.6
Caudate	R		14.75	18	-12	24		0.9
Precuneus	R	622	30.57	10	-68	28	**< 0.001**	**0.02**
Cuneus	R		24.77	14	-68	38		0.2
Cuneus	L		19.95	-16	-64	26		0.6
Thalamus	L	200	28.99	-8	-10	8	**0.002**	**0.04**
Thalamus	L		16.41	-6	-14	-2		0.9
Thalamus	L		14.03	-6	-20	4		0.9
Caudate	L	117	28.72	-14	10	16	**0.03**	**0.04**
Caudate	L		18.42	-16	16	8		0.7
Middle cingulate cortex	L	724	27.52	6	-28	26	**< 0.001**	0.06
Middle cingulate cortex	L		27.21	0	-34	50		0.07
Middle cingulate cortex	L		25.67	-4	-30	40		0.11
Rolandic operculum	L	341	24.78	-40	-14	18	**< 0.001**	0.15
Rolandic operculum	L		20.18	-52	-6	8		0.55

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
Rolandic operculum	L		20.12	-46	-20	18		0.56
Precuneus	R	132	23.45	12	-48	74	**0.02**	0.23
Precuneus	R		21.44	10	-48	66		0.4
Rolandic operculum	R	454	22.53	58	-2	8	**< 0.001**	0.3
Insula	R		20.66	36	6	14		0.5
Rolandic operculum	R		20.44	48	-8	12		0.52
Supramarginal gyrus	L	113	21.41	-64	-32	34	**0.04**	0.41
Supramarginal gyrus	L		18.95	-56	-28	36		0.71
Superior temporal gyrus	R	125	18.26	64	-22	16	**0.03**	0.8
Supramarginal gyrus	R		17.49	58	-26	20		0.87

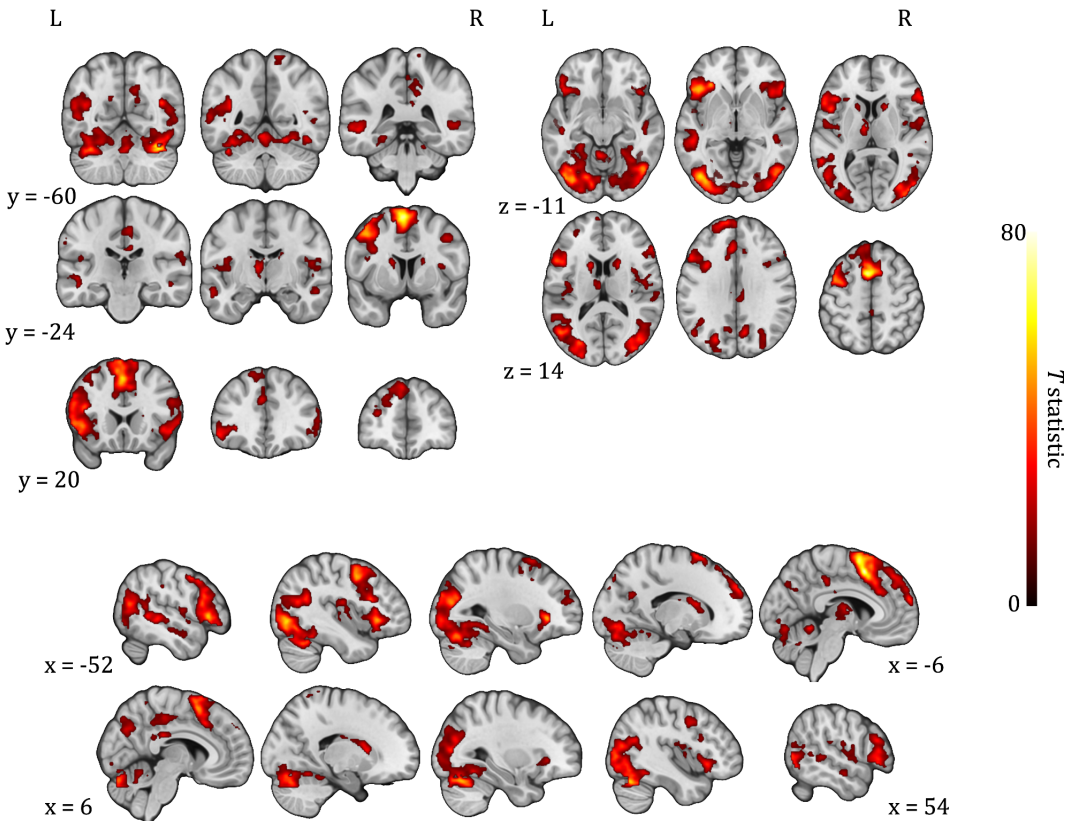

Figure 24. Whole-brain statistical parametric maps representing brain activation for the main effect of emotion regulation. The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 113 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

A paired t-test was used to identify regions activated by CR or MA across all participants (REAP > MIND and MIND > REAP). CR in comparison to MA involved greater activation in the right middle temporal gyrus ($p < 0.001$ FWEc corrected with cluster-level extent threshold of $p < 0.05$ and cluster size of k = 128 voxels, Table 11 and Figure 25). The comparison of MA to CR did not reveal significant differences.

Table 11. Differences in brain activation between ER strategies for all participants (REAP > MIND and MIND > REAP contrasts). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 128 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
REAP > MIND								
Middle temporal gyrus	R	128	4.24	58	-6	-18	**0.05**	0.57
Middle temporal gyrus	R		3.91	54	2	-22		0.86
Superior temporal pole	R		3.85	50	12	-20		0.86
MIND > REAP								
No suprathreshold clusters								

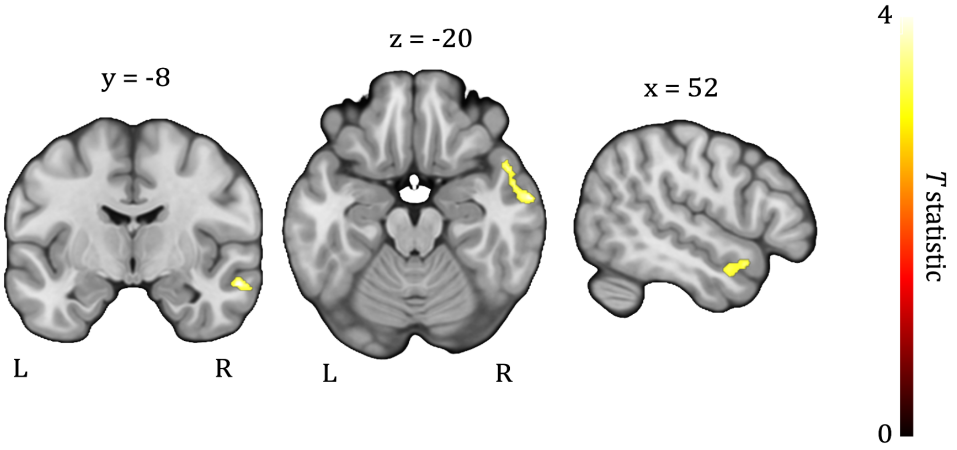

Figure 25. Whole-brain statistical parametric maps representing brain activation for the CR in comparison to MA (REAP > MIND). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 128 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

The analysis of the main effect of group revealed no significant results (REAP+MIND > 2x$VIEW_{SAD}$). A paired t-test was used to identify regions modulated by CR only (CR > $VIEW_{SAD\_REAP}$) and it resulted in a large cluster of heightened activation within, for example, the caudate, middle temporal gyri, precentral gyri, middle frontal gyri, supplementary motor cortex, ACC, SFG, angular gyri, and occipital cortex ($p < 0.001$ FWEc corrected with cluster-level extent threshold of $p < 0.05$ and cluster size of k = 144 voxels, Table 12 and Figure 26).

Table 12. Differences in brain activation between CR and $VIEW_{SAD}$ from this run (REAP > $VIEW_{SAD\_REAP}$). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 128 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
REAP > VIEW$_{SAD}$								
Inferior temporal gyrus	R	43390	9.6	48	-66	-10	**< 0.001**	**< 0.001**
Cerebellum	R		9.33	40	-66	-26		**< 0.001**
Supplementary motor cortex	L		9.33	-4	6	62		**< 0.001**
Cuneus	R	144	5.22	24	-54	20	**0.03**	**0.03**
Calcarine cortex	R		4.47	22	-54	12		0.34

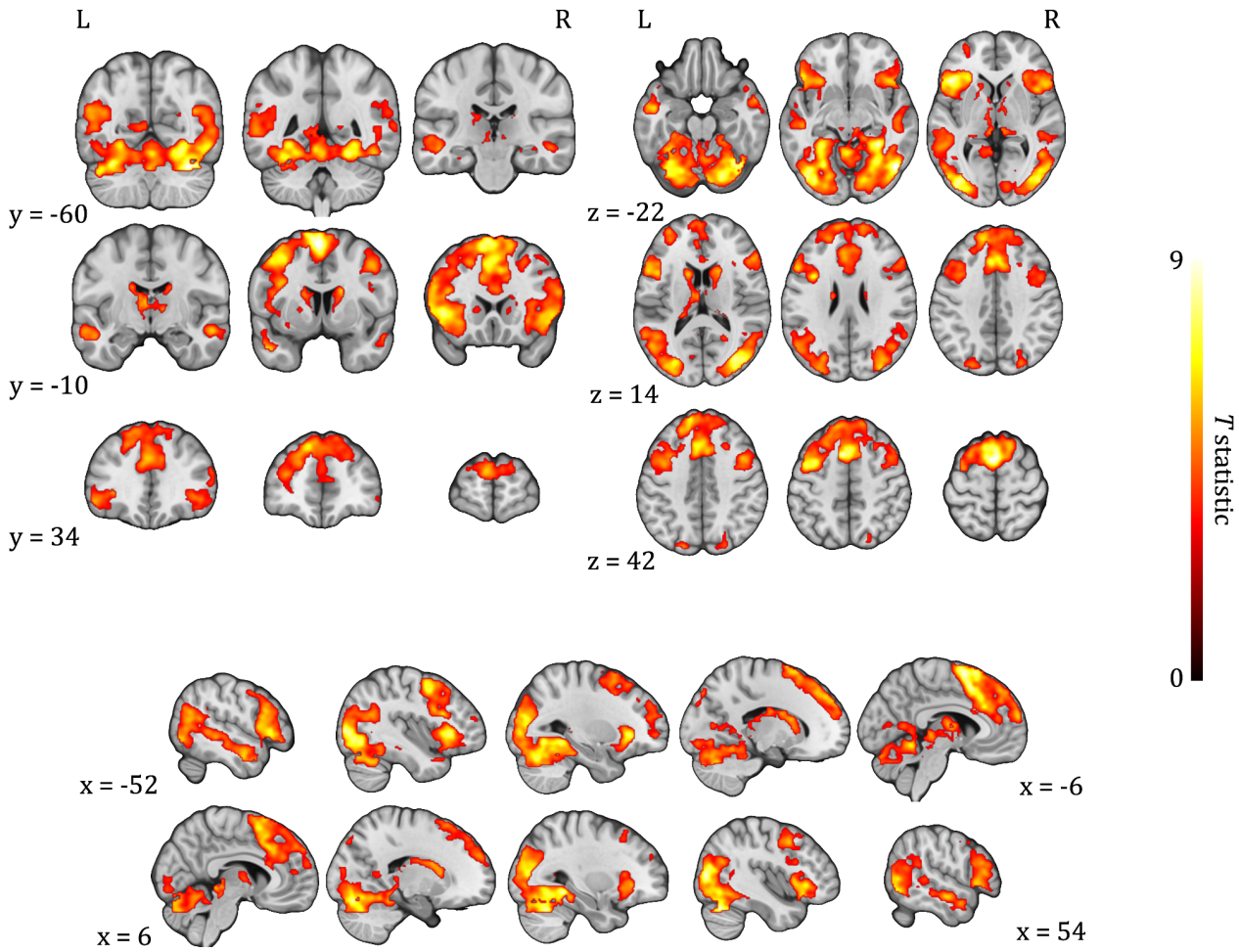

Figure 26. Whole-brain statistical parametric maps representing brain activation modulated by the CR (REAP > $VIEW_{SAD\_REAP}$). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 144 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

Another paired t-test was used to identify regions modulated by MA only (MA > $VIEW_{SAD\_MIND}$). This analysis revealed significantly higher activations during MA within the lingual gyrus, supplementary motor cortex, middle frontal gyrus, and precentral gyrus ($p < 0.001$ FWEc corrected with cluster-level extent threshold of $p < 0.05$ and cluster size of k = 317 voxels, Table 13 and Figure 27).

Table 13. Differences in brain activation between MA and $VIEW_{SAD}$ from this run (MIND > $VIEW_{SAD\_MIND}$). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 317 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
MIND > VIEW$_{SAD}$								
Lingual gyrus	L	351	6.72	-10	-84	-8	**< 0.001**	**< 0.001**
Supplementary motor cortex	L	522	5.64	-8	10	52	**< 0.001**	**0.01**
Supplementary motor cortex	L		4.9	-6	6	64		0.08
Supplementary motor cortex	L		4.78	-4	14	70		0.15
Middle frontal gyrus	L	317	5.38	-44	6	54	**< 0.001**	**0.02**
Precentral gyrus	L		5.2	-50	4	48		**0.04**
Precentral gyrus	L		4.72	-52	12	42		0.18

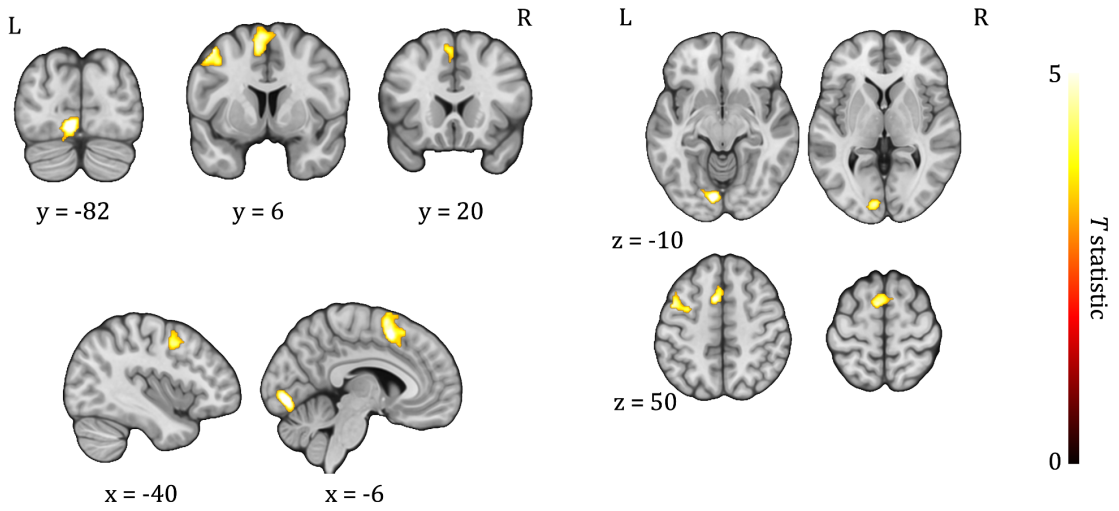

Figure 27. Whole-brain statistical parametric maps representing brain activation modulated by the MA (MIND > $VIEW_{SAD\_MIND}$). The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 317 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

A flexible factorial analysis, used to test for the interaction between group and ER strategy revealed a significant result in a cluster spanning over the angular gyrus,

supramarginal gyrus, and inferior parietal gyrus (p < 0.001 FWEc corrected with cluster-level extent threshold of p < 0.05 and cluster size of k = 169 voxels; the result is presented in Supplementary Material 5.7). However, the post hoc tests did not reveal any significant differences. There were no significant results revealed by analyses testing research questions Q8, Q9, and Q10, which explored possible differences between MDD and HC, and BPD and HC in CR processing, as well as possible differences between all groups for MA processing.

ROI results. The analysis testing hypothesis H8, stating that BPD group will show lower activation within the DLPFC, DMPFC, VLPFC and higher activation in the amygdala and insula during CR than the HC group, did not reveal significant results.

Functional connectivity results. Hierarchical clustering procedure, performed on data taken from all participants, revealed 3 clusters. Cluster A included bilateral amygdalae, Cluster B included right MFG/dmPFC and right ACC, and Cluster C included right SFG/dlPFC, left insula, and left IFG/vlPFC.

The analysis of the main effect of emotion regulation (REAP+MIND > $2xVIEW_{SAD}$) revealed decreased connectivity within the Cluster C ($F(3, 79) = 4.80$, p uncorrected = 0.004, p FDR-corrected = 0.024). However, the connection within that cluster, between the right SFG and left IFG ROIs, did not remain significant after FDR correction (T = -2.57, p uncorrected = 0.01, p FDR-corrected = 0.07). All the remaining analyses did not reveal significant results.

3. Discussion

Major depressive disorder and borderline personality disorder are very debilitating mental health conditions, causing deterioration of the quality of life of an individual and negatively impacting the socio-economic system. Despite them being different clinical units, they often co-occur and share some of the symptoms, such as difficulties with emotion regulation or with processing the self, which is intertwined with such processes as autobiographical memory recall.

The study described in the present dissertation aimed to explore possible differences and commonalities between these disorders, in two major processes - autobiographical memory recall and emotion regulation. To the best of my knowledge, this is the first fMRI study that a) compared MDD and BPD groups during autobiographical recall of sad and happy memories, and b) compared these groups in an emotion regulation task with both cognitive reappraisal and mindful acceptance.

Below, I will first discuss the results of the autobiographical memory task, then the results of the emotion regulation task, lack of the expected between-group differences, and in the end, I will describe some of the study's limitations.

3.1. The autobiographical memory recall

This part of the study aimed to test the behavioral and neural responses during recall of sad and happy memories in women with MDD, BPD, and healthy control. The only studies previously looking at AM recall in both disorders simultaneously were comparing self-reported memories in terms of their specificity (Arntz et al., 2002; Renneberg et al., 2005; Rosenbach and Renneberg, 2015). Moreover, the present study was the first to investigate sad and happy memories in BPD. In the previous studies on BPD only negative resolved or unresolved memories were used (Beblo et al., 2006; Bozzatello et al., 2019; Driessen et al., 2004).

As expected (H1a), emotional state of the depressed participants was subjectively sadder after the sad AM recall, than in the control group. However, no differences for sad recall were found between the BPD and HC groups (H1b). In accordance with another hypothesis (H2b), the BPD group rated their emotional state as less happy after happy recall than HC, while on the other hand, MDD and HC did not differ significantly for happy AMs (H2a). At the same time, there were no differences in emotional state between the clinical groups, regardless of memory type. Interestingly, these results show that MDD and BPD may variously differ from

healthy individuals depending on a type of memories. Both in assessment during the scan and assessment of memories on additional scales, women with depression differed from the healthy control primarily regarding sad AMs. Participants with MDD rated sad AMs as more arousing, therefore confirming hypothesis H3a, as well as related to more surprise, anger, disgust, and fear. On the other hand, women with BPD differed significantly from the HC in the fMRI emotional state ratings only after happy recall. In case of the additional scales, they differed from HC in ratings of both types of AMs. The BPD group had higher scores of arousal and disgust for sad AMs, and higher scores of surprise, anger, and fear for both sad and happy memories. It could be suggested that, while subjective perception of own sad memories may distinguish both MDD and BPD from HC, BPD may be additionally distinguished from HC with happy memories, while it is not necessarily true for depression. To my knowledge, no other study asked participants to rate their memories in terms of basic emotions.

Additionally, the MDD and BPD groups rated all memories taken together as related to more arousal than the HC group. This result between MDD and HC is inconsistent with previous research that showed no differences (Young et al., 2013) or lower arousal ratings in a depressed group (Young et al., 2012). However, those studies had smaller sample sizes (16MDD/16HC and 12MDD/14HC, respectively) and therefore were less representative of the populations.

Despite the lack of significant differences between the clinical groups in the emotional state ratings, there were several significant results in the additional scales assessment. Regardless of the memory type, the BPD group rated anger, disgust, and fear as higher than the MDD group. Moreover, women with BPD specifically rated their happy AMs as related to more fear than the depressed participants did. The groups did not vary in sadness or happiness ratings. Therefore, MDD and BPD may perceive sadness or happiness in their memories similarly. What distinguishes them may be other basic emotions. These basic emotions are more in line with clinical image of BPD than MDD. A meta-analysis by Kohling et al. (2015) showed that people with BPD may experience more anger, hostility, or self-directed disgust.

Differences in emotional state and additional scales ratings are most likely arising from subjective perception of participants' experiences and disparities in intensity of their emotions. However, these differences may also result from objective distinctions of contents or type of experiences. Although majority of results of the independent judges' ratings were insignificant (Supplementary Materials 5.5.), they showed that memories of the BPD group were in general less positive (i.e., had lower valence ratings) than memories of the HC group. Lower valence ratings were also found in the subjective ratings - BPD had in general lower valence ratings than the MDD and HC groups. Does it mean that women with BPD may universally experience more

negative events? It may be possible since the development of this disorder is often linked to childhood trauma and unsafe environment (Linehan, 1993), while major depression is not always related to childhood adversities and may also be a reaction to adverse situations or prolonged stress (Hammen, 2015).

Subjective ratings of vividness revealed that across all participants sad AMs were rated as less vivid than happy and neutral ones. This was also observed for ratings within the MDD and HC groups, but no difference was found in BPD participants. Lower vividness ratings of sad than happy memories are consistent with results from a study by Lindeman et al. (2017) in a group of healthy participants. The authors showed that positive memories were recalled more vividly than sad ones, and that affect related to positive AMs faded less than for negative memories. This effect is called a *fading affect bias* - negative emotions related to negative AMs tend to fade over time more quickly (Skowronski et al., 2014). The lack of differences between the MDD and HC groups in the present dissertation was in line with previous studies (Young, Bodurka, et al., 2016; Young et al., 2013, 2014).

The main effect of AM recall from the neuroimaging data resulted in activations within brain regions previously implicated and reported as crucial for this type of memory: occipital cortex, middle temporal lobe regions, precentral and postcentral gyri, angular gyrus, ACC, insula, among other regions (Cabeza & St Jacques, 2007; Iriye & Jacques, 2018; Kim, 2012; Spreng et al., 2009; St. Jacques, 2012; Svoboda et al., 2006). When the sad and happy memories were compared to each other, across all participants taken together, significantly stronger brain activation was obtained only for sad AMs in regions of the left mPFC and dmPFC, angular gyrus, PCC, and right insular cortex. No significantly greater activations were noted for the happy AMs. Medial prefrontal cortex, as well as PCC, are often considered crucial for processing self-relevant information during AM recall (Cabeza & St Jacques, 2007; Cavanna & Trimble, 2006; Denny et al., 2012; St. Jacques, 2012). Perhaps the sad memories included more information about the self. It would be contrary to previous studies which showed that happy AMs could contain more self-relevant information (Suardi et al., 2016), however, those studies only included healthy participants. Because the insular cortex is related to processing bodily states and body awareness (Seth & Friston, 2016), sad AMs may influence greater responses of the body during recall. However, because there was also a greater activation of TPJ, which engages in mental imagery of one's body (Blanke et al., 2005) and in shifts of perspective during imagery (Krall et al., 2015), sad memories could also be related to more visualizations of one's body during the past event. Because the vividness ratings were lower for sad AMs, this activation can also suggest greater effort put into visual imagery during the recall. Additionally, greater

activation of the angular gyrus suggests that sad AMs demand more processing of semantic knowledge (Humphreys & Lambon Ralph, 2015) or more effort to be successfully recollected (Rugg & King, 2018). Lack of significantly stronger activations for happy AMs is inconsistent with previous studies that showed stronger engagement of, for example, OFC, mPFC, precuneus, or temporal cortex (Markowitsch et al., 2003; Pelletier et al., 2003; Speer et al., 2014; van Schie et al., 2019). This could mean that in the present study the happy AMs were less engaging or perhaps easier to recall than sad events. Moreover, samples in those studies were predominantly very small - 9-20 healthy participants, with the exception of 47 in the study by van Schie et al. (2019) – and may not reflect reliable results.

Contrary to hypotheses (H4a-c) the neuroimaging results of the AM task did not show expected between-group differences, especially during the sad memory recall. Also, the study did not replicate previously reported differences between people with MDD and HC, for example: diminished activation in MDD in regions of the PFC or MTG during recall in general (Young et al., 2012), lower activation of regions in the parietal and limbic cortices and higher activation of MTG and PFC regions for positive AMs (Young, Bodurka, et al., 2016; Young et al., 2014; Young, Siegle, et al., 2016), or higher activation of the ACC, amygdala, and hippocampus for negative memories (Young, Bodurka et al., 2016; Young et al., 2014). There may be several explanations for this lack of results. It is possible that collecting the memories from participants a couple of days before the fMRI scan affected the results. This method has a risk of rehearsing the memories or recalling them from the interview perspective (Cabeza & St. Jacques, 2007). On the other hand, people with MDD and BPD tend to ruminate (Daros & Wiliams, 2019; Nolen-Hoeksema et al., 2008) and maybe frequent rumination of past experiences diminishes the needed effort to recall them. Additionally, the literature is often inconsistent. For example, behavioral studies comparing overgeneral memories between MDD and BPD showed either overgenerality only in MDD (Arntz et al., 2002; Renneberg et al., 2005) or no differences (Rosenbach & Renneberg, 2015).

The functional connectivity analysis for the main effect of recall revealed significantly heightened connectivity between all the regions of interest. These results support the current literature's claims that those regions may be the most crucial for AM recall and that they could constitute an AM network (Kim, 2012; Spreng, 2009; Svoboda, 2006). Further analyses showed that, in comparison to happy memories, sad ones resulted in greater positive connectivity between multiple regions. Increased connectivity of the vmPFC with insula and AG suggests that sad memories rely more strongly on recollection and integration of self-relevant information (vmPFC), emotional and bodily information processing (insula), and semantic

recollection (AG; Humphreys & Lambon Ralph, 2014; Rugg & King, 2018). The sad AMs recall also resulted in greater connectivity between the amygdala and hippocampus. Previous studies showed this relationship as present in AM recall in general and suggested that enhanced emotional processing amplifies memory search and recollection (e.g., Daselaar et al., 2008; Markowitsch et al., 2000). Therefore, sad memories may depend more on this mechanism. Heightened connectivity for sad AMs was also noted between the precuneus and amygdala, and between precuneus and hippocampi. Previous works claim that visual imagery enhances recollection of AMs and emotional importance of these events (Holmes, Coughtrey, et al., 2008; Holmes, Mathews, et al., 2008). Because of lower behavioral vividness ratings for the sad AMs, the connectivity result suggests that faded memories may need greater cooperation between retrieval of contextual details and visual processing (precuneus), emotional processing (amygdala), and memory recollection (hippocampus). Lack of increased functional connectivity for the happy AMs, as compared to sad ones, suggests that their recollection may have been less engaging.

The main effect of group in the connectivity analyses was significant, and it was driven by the differences between both clinical groups taken together and the HC group. The result showed a greater positive correlation between the activity of the left precuneus and right occipital cortex for the MDD and BPD groups. One possible explanation is that in these disorders vivid AM recall requires stronger cooperation of regions engaged in visual imagery (occipital cortex) and in recollection of contextual details (precuneus). In clinical groups imagery may also be connected to stronger self-processing, since the precuneus is additionally involved in processing the self. Previous studies have also shown that precuneus may be engaged in taking the third-person perspective during AM recall (Grol et al., 2017) and that its activity raises when a person distances themselves from negatively valenced stimuli (Koenigsberg et al., 2009). The clinical groups in the present study could have taken the third-person perspective more often in order to distance themselves from these emotional experiences. However, I did not control for the memories' perspective and there were no group differences for the sole activity of precuneus. As this is a single result, not reported before, further investigation is needed.

Further possible reasons for lack of significant group differences are discussed in the section 3.3.

3.2. The emotion regulation

This part of the study aimed at measuring the influence of two adaptive regulation strategies - cognitive reappraisal and mindful acceptance - on behavioral and neural responses in women with MDD, BPD, and healthy control. Very recently new fMRI studies were published comparing these groups during CR regulation (either using positive reappraisal or distancing; De la Peña-Arteaga et al. 2021; Wainsztein et al., 2021). The present study, according to my knowledge, is the first fMRI study to additionally compare MDD, BPD, and HC in the MA strategy.

The analysis of behavioral data showed that after emotion regulation in general participants rated their emotional state as more positive than when viewing sad pictures. When the strategies were compared to control condition separately, the same result was observed for the CR strategy, however, emotional state did not differ between MA and viewing condition. Moreover, emotions were rated as less sad after CR than after MA. This is consistent with studies showing greater subjective effectiveness of CR than MA in reducing negative emotions (Goldin et al., 2019; Smoski et al., 2015; Troy et al., 2018). Cognitive reappraisal was also related to less sad emotional state than MA within the MDD and BPD groups. Unexpectedly (H5), I did not find significant differences between the groups for their ratings of emotional state after emotion regulation. However, this lack of differences is not rare. Meta-analysis by Daros and Williams (2019) showed that people with BPD were not different from healthy controls in downregulation, while meta-analysis by Zilverstand et al. (2017) showed that only 5 studies out of analyzed 32 reported significant differences between HC and clinical groups.

Success in following the instructions was rated as higher after MA than after CR trials. The results of emotions and success are in line with the study by Troy et al. (2018) which showed that participants rated MA instructions as easier to follow than CR, but the MA strategy did not significantly lower their negative emotions. It seems that for people with no prior training in mindfulness or reappraisal, focusing on current thoughts appears easier than coming up with a new interpretation for a stimulus. Nevertheless, it does not improve negative emotions. Perhaps lack of experience in using adaptive ER strategies is less important for efficacy of CR.

Additionally, participants from either clinical group rated themselves as less successful than HC throughout the whole task. Previous work showed that patients perceived themselves as less effective in using adaptive ER strategies than healthy people (Daros et al., 2020), including reappraisal (Sauer et al., 2016). However, in the present study it appears that they perceived themselves as less effective regardless of instructions.

The main effect of emotion regulation from the neuroimaging data resulted in activations within brain regions previously reported to be involved in ER, especially the frontal gyri, supplementary motor cortex, precuneus, or supramarginal gyrus (Buhle et al., 2014; Clark-Polner et al., 2016; Ochsner, Silvers, & Buhle, 2012). Contrary to expectations (H6), no significant differences in the whole brain activation were found between the groups. The functional connectivity analysis of the main effect of regulation revealed only one significant cluster with a connection between the right superior frontal gyrus and left inferior frontal gyrus. However, this connection itself was not significant.

Contrary to hypotheses the behavioral and neuroimaging results of the ER task did not show expected significant between-group differences. Also, the study did not replicate previously reported differences between MDD and HC (e.g., Johnstone et al., 2007; Keller et al., 2022) or between BPD and HC groups (e.g., Koenigsberg et al., 2009; Schulze et al., 2011). Lack of difference in PFC activation between the MDD and HC groups could be explained by a previous review which showed that during voluntary and instructed ER people with depression may have equal activation of prefrontal regions when compared to HC (Rive et al., 2013). There are other possible explanations for the lack of expected results. Only half of data gathered was used due to error in the procedure, therefore supposedly its amount was insufficient to obtain more meaningful results. Interestingly, however, not all studies show differences in ER difficulties between MDD and BPD (for example Carvalho Fernando et al., 2014). Also, the stimuli used in the study depicted situations that may not have been salient for the groups. Information that is not salient may not elicit dysregulation and emotional responses may be easier to regulate (especially in BPD, e.g., Daros et al., 2013). Further discussion of the lack of between-group differences is presented below.

3.3. The lack of between-group differences

Presented study showed that both tasks worked as planned and engaged activity of their respective core brain regions. The main effect of AM recall showed increased activation in regions of the mPFC, limbic system, MTG, and posterior regions such as PCC or precuneus. All those brain areas have been previously reported as important for this type of memory recollection (Cabeza & St Jacques, 2007; Iriye & Jacques, 2018; Kim, 2012; Spreng et al., 2009; St. Jacques, 2012; Svoboda et al., 2006). Also, the main effect of emotion regulation showed successful engagement of frontal gyri, supplementary motor cortex, precuneus, or

supramarginal gyrus, among other regions, which has been shown in ER literature (Buhle et al., 2014; Clark-Polner et al., 2016; Ochsner et al., 2012). These main effects' results suggest that the task designs were effective and that participants were engaged in the tasks.

Even though the study showed the effectiveness of both tasks, expected between-group results were not obtained. However, predominant lack of differences is consistent across the whole study. Several more general reasons for the lack of those differences can be proposed, aside of those already mentioned in the chapters above. First, the participants' symptoms could have been too mild. Most participants were very well-functioning, despite the ongoing depressive episode or years of personality pathology. Second, such passive paradigms rely mostly on internal mental responses, contrary to more behaviorally engaging tasks. Even though both tasks were designed to be more ecologically valid, they give little control over participants' behavior. Third, discrepancies between studies' results are common in the literature, possibly due to variations in task paradigms, stimuli, or studied samples. Some of the studies do not report whether participants were taking medication or not, or how this variable could have impacted the results. Considering that MDD and BPD are heterogenous (e.g., Drevets, 2000; Smits et al., 2017), group differences may occur less frequently. It is also difficult to define how often the lack of differences occurs because the literature is burdened with the positive-results bias and the null results are less likely to be published. The literature that I based my research on studied similar BPD samples or even smaller ones (for example, 15-24 participants) and succeeded in obtaining significant group differences (e.g., Bozzatello et al., 2019; Scherpiet et al., 2015; Schulze et al., 2011). Literature on MDD mostly studied even smaller samples (e.g., 12-16 participants, Young, Bodurka, et al., 2016; Young et al., 2012, 2013, 2014). Therefore, the results presented in this dissertation should be more reliable. Furthermore, majority of the analyses were planned a priori and some of them were focused on regions of interest analysis, which is a sensitive method.

3.4. Limitations

The presented study has several limitations. The studied groups could be described as medium to small sample sizes, especially the BPD group which was downsized to 18 participants after medicated participants were excluded from the analyses. Recruitment of even bigger samples of women with depression or BPD is difficult. These women have usually co-occurring disorders, have prescribed multiple medications, and are more prone to drop-out

from a study. However, as described above, the studied sample sizes were not smaller than in the previous studies.

Regarding the AM task, the procedure for gathering the memories could provide additional limitations. The pre-scan interview could have influenced rehearsal of memories before the scan. Additionally, the memories were not gathered based on how recent or remote they were. Some studies suggest that remoteness influences neural processing of AMs (e.g., Steinvorth et al., 2006), while others show that it does not influence, for example, the activity of hippocampus (Addis et al., 2004; McCormick et al., 2020).

Half of the data from the emotion regulation task was lost due to an error in task paradigm. Remaining analyzed data could have been insufficient to obtain more reliable and meaningful results.

Another limitation could be exclusion of male participants. Thus, the results do not relate to a broader population of people suffering from MDD or BPD. However, this was decided based on the prevalence of these disorders in the general population. Women are more often diagnosed with those disorders than men and therefore are easier to recruit for a study.

3.5. Concluding remarks

The study described in the present dissertation aimed to explore differences and common characteristics between major depressive disorder and borderline personality disorder in two processes – autobiographical memory recall and emotion regulation.

The tasks engaged brain regions previously reported in the literature on those processes. These results showed that task designs were effective and that participants engaged in the tasks instructions. Despite this, the expected between-group results were not observed. This could have been caused by several reasons, including heterogeneity of MDD and BPD.

Nevertheless, the presented findings suggest that autobiographical memory is a process that could help in distinguishing MDD and BPD from healthy population. Even if AM results did not show differences between these disorders, they did show how MDD and BPD may differ from healthy individuals differently at the behavioral level. While in MDD the reaction to sad stimuli could be more distinct than in HC, the BPD group could perceive differently both sad and happy memories than HC. At the same time, the study showed how both clinical groups could similarly differ from HC at the neural level based on shared functional connectivity between the precuneus and occipital cortex.

Future research could propose additional measures to improve control over participants' behavior during such naturalistic paradigms, for example, additional questions during the fMRI scan. Future studies could also more strongly control the heterogeneity of the disorders by measuring additional traits and groups of symptoms – such as anxiety, impulsivity, or dissociation. I hope that this study will motivate larger-scale studies of MDD and BPD which will shed light on various mechanisms that these disorders do and do not share.

4. References

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5. Supplementary materials

5.1. Diagnostic criteria for major depression and borderline personality disorder

At the time of the study ICD-10 and DSM-5 were in force as diagnostic manuals.

Table S1. Diagnostic criteria for major depressive disorder based on International Classification of Diseases, 10th Edition (ICD-10) and Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5).

ICD-10 criteria for depression
In the ICD-10 depressive episodes are distinguished between mild, moderate, and severe based on the number and severity of symptoms. Minimum duration of an episode should be 2 weeks for a diagnosis but if the symptoms are very severe or have a rapid onset, a diagnosis can be made after a shorter time. A depressive episode can be characterized by: - depressed mood - loss of interest and enjoyment - reduced energy leading to fatigability and tiredness - reduced concentration and attention - reduced self-esteem - feelings of guilt and unworthiness - pessimistic views of the future - thoughts/plans/acts of self-harm or suicide - disturbed sleep - diminished appetite.
DSM-5 criteria for depression
Major depressive episodes last at least 2 weeks but usually considerably longer. They involve changes in affect, cognition, and neurovegetative functions. An episode is diagnosed based on five or more of the following symptoms, which are present almost every day: - persistent depressed mood - diminished interest or pleasure in daily activities - weight loss or weight gain, and decreased or increased appetite - insomnia or hypersomnia - psychomotor agitation or retardation - loss of energy, fatigue - feelings of worthlessness, guilt - difficulties with concentration; indecisiveness - recurrent thoughts of death, suicidal ideation, suicide plans or attempts The DSM-5 also distinguishes between mild, moderate, and severe depressive episodes.

Table S2. Diagnostic criteria for borderline personality disorder based on ICD-10 and DSM-5 classifications.

ICD-10 criteria for borderline personality disorder
This personality disorder is named in the ICD-10 as e*motionally unstable personality disorder.* It is characterized by a tendency to act impulsively without concern for the consequences, lack of self-control, affective instability, and feelings of intense anger. It is divided into two types: *impulsive* and *borderline*. Impulsive type is mainly characterized by: - emotional instability - lack of impulse control - outbursts of violence Borderline type is mainly characterized by: - instability of emotions, identity, self-image, goals, and preferences - chronic feelings of emptiness - involvement in intense and unstable relationships - excessive efforts to avoid abandonment - suicidal threats or acts, and acts of self-harm
DSM-5 criteria for borderline personality disorder
Borderline personality disorder is diagnosed in the presence of five or more of the following symptoms: - intense efforts to avoid abandonment, either real or imagined, - unstable and intense relationships, alternation between idealization and devaluation of another person, - identity disturbance, including unstable sense of self, life goals, opinions, sexual identity, - impulsivity, for example reckless driving, gambling, substance abuse, binge eating, - suicidal behavior or threats, self-harm - affective instability - feelings of emptiness - intense, inappropriate anger and irritability - stress-related paranoid ideation or dissociative symptoms

5.2. List of general questions regarding health in the online recruitment questionnaire

Participants responded to a list of yes-no questions. The questions were as follows (next to each question is provided its English translation):

1. Czy miała Pani w przeszłości zdiagnozowany epizod depresji? (*Were you diagnosed with a depressive episode in the past?*)
    a. TAK → Ile epizodów? (*YES → How many episodes?*)
2. Czy uważa Pani, że obecnie ma depresję? (*Do you believe that currently you are depressed?)*

a. TAK → Który epizod? *(YES → Which episode?)*

3. Czy obecnie zażywa Pani leki przeciwdepresyjne? (*Are you currently taking antidepressant medication?)*
    a. TAK → Prosze podać nazwę i dawkę (*YES → Please provide a name and dosage)*
    b. Czy przez ostatnie 6 tygodni dawka była stabilna (tzn. bez zmian)? (*Was the dosage stable during the past 6 weeks (i.e., no changes)?)*
4. Czy obecnie zażywa Pani inne leki, w tym wpływające na układ nerwowy? (*Are you currently taking other medication, including those influencing the nervous system?)*
    a. TAK → Jakie? Proszę podać nazwę (*YES → Which ones? Please provide a name)*
5. Czy ma Pani zdiagnozowane inne choroby lub zaburzenia psychiatryczne, w tym zaburzenia osobowości? (*Were you diagnosed with other psychiatric disorders, including personality disorders?)*
    a. TAK → Jakie? (*YES → Which ones?)*
6. Czy ma Pani zdiagnozowane choroby lub zaburzenia neurologiczne? (*Were you diagnosed with neurological disorders?)*
    a. TAK → Jakie? *(YES → Which ones?)*
7. Czy miała Pani uraz głowy/mózgu wymagający hospitalizacji? (*Did you suffer from a head/brain injury which needed hospitalization?)*
    a. TAK → Jaki i kiedy? *(YES → What kind of injury and when?)*
8. Czy ma Pani zdiagnozowane inne choroby przewlekłe? (*Were you diagnosed with other long-term disorders?)*
    a. TAK → Proszę podać jakie (*YES → Please provide what kind of disorders)*
9. Czy w ostatnich kilku dniach doświadczała Pani myśli samobójczych? (*Did you experience suicidal thoughts in the past few days?)*
10. Czy doświadcza Pani bardzo podwyższonego nastroju („euforia") na zmianę z bardzo obniżonym? (*Do you experience a very high emotional state ("euphoria") alternating with a very low state?)*
11. Czy spożywa Pani alkohol lub inne używki (z wyjątkiem papierosów i kawy) częściej niż 4 razy w tygodniu? (*Are you drinking alcohol or taking other substances (except for cigarettes and coffee) more frequently than 4 times a week?)*
12. Czy brała Pani udział w psychoterapii w ostatnich 6 miesiącach? (*Did you participate in a psychotherapy in the past 6 months?)*
13. Czy obecnie uczestniczy Pani w psychoterapii? (*Do you currently participate in psychotherapy?)*

a. TAK → W jakim typie? (*YES → Which type?)*

14. Czy posiada Pani metalowe elementy w ciele (np. rozrusznik, endoproteza, metalowe śruby, a także makijaż permanentny, tatuaże na twarzy i głowie, piercing na twarzy (trzeba zdjąć do badania w rezonansie))? (*Do you have metal objects in your body (e.g., pacemaker, endoprosthesis, metal screws, and permanent makeup, tattoos on face and head, piercing on face (should be taken off during the MRI session))?)*
    a. TAK → Jakie? (*YES → Which/What kind?)*
15. Czy ma Pani klaustrofobię (lęk przed ciasnymi pomieszczeniami)? (*Are you claustrophobic (fear of tight spaces)?)*
16. Czy jest Pani praworęczna? (*Are you right-handed?)*
17. Czy jest lub może być Pani w ciąży? (*Are you or may you be pregnant?)*

5.3. Examples of memories provided by three participants and the memories' cues

Below are examples of one sad memory, one happy memory, and one neutral situation for three different participants.

Table S3. Examples of memories and memory cues from three participants.

	Memory/cue type	English version	Polish version
Participant 1	Sad memory	When my fiancé forgot about our first anniversary and spent it with his friends, and it still „sits" in me very hard.	Jak mój narzeczony zapomniał o naszej pierwszej rocznicy i spędził ją z kolegami i to mocno we mnie siedzi.
	Sad memory cue	Recall *forgetting about the first anniversary.*	Przypomnij sobie *zapomnienie o pierwszej rocznicy*.
	Happy memory	I picked up my current cat from [city name] and it was my first contact with a bald cat.	Odebrałam mojego aktualnego kota z [nazwa miasta] i to był mój pierwszy kontakt z łysym kotem.
	Happy memory cue	Recall *picking up a cat from* [city name].	Przypomnij sobie *odebranie kota z* [nazwa miasta].
	Neutral situation	Brushing teeth.	Mycie zębów.
	Neutral situation cue	Recall the last time you *brushed your teeth.*	Przypomnij sobie jak ostatnio *myłaś zęby.*

	Memory/cue type	English version	Polish version
Participant 2	Sad memory	When my boyfriend after 3,5 years told me that he doesn't know if he loves me and broke up with me.	Jak mój chłopak po 3,5 roku powiedział, że w sumie to nie wie czy mnie kocha i zerwał ze mną.
	Sad memory cue	Recall *the breakup after 3,5 years.*	Przypomnij sobie *zerwanie po 3,5 roku.*
	Happy memory	Swimming in a lake at night. This was my first sailing trip, we were sailing most of the day, then a bonfire. When it was dark already, we were going to swim in a lake. It was a mega starry night.	Kąpiel w nocy w jeziorze. To były pierwsze żagle, większość dnia żeglowaliśmy, potem jakieś ognisko. Jak już było ciemno, to chodziliśmy się myć do jeziora. Była mega rozgwieżdżona noc.
	Happy memory cue	Recall *swimming in a lake at night.*	Przypomnij sobie *kąpiel w nocy w jeziorze.*
	Neutral situation	Eating dinner.	Jedzenie obiadu.
	Neutral situation cue	Recall the last time you *were eating dinner*.	Przypomnij sobie jak ostatnio *jadłaś obiad.*
Participant 3	Sad memory	In April [year] my dad called me with the news that my grandmother had died. She was sick for a while, so it wasn't a big surprise, but it was very sad in itself. The next day we were supposed to go to her, and we didn't make it.	W kwietniu [rok] zadzwonił tata do mnie z wiadomością, że zmarła moja babcia. Chorowała przez jakiś czas, więc to nie było zaskoczenie. Ale samo w sobie było bardzo przykre. Następnego dnia mieliśmy do niej jechać i się nie udało.
	Sad memory cue	Recall *your grandmother's death.*	Przypomnij sobie *śmierć babci.*
	Happy memory	Passing my driving license test was a joyful moment. Unfortunately, I failed the 1st time, but not during the first time, and I was able to pass with a lady who was widely known to be rigorous.	Zdanie prawa jazdy było radosnym momentem. Nie udało się niestety za 1 razem, ale już za tym kolejnym i udało mi się zdać z panią, która powszechnie była znana jako rygorystyczna.
	Happy memory cue	Recall *passing driver's license test.*	Przypomnij sobie *zdanie prawa jazdy.*
	Neutral situation	Washing hair.	Mycie głowy.

	Memory/cue type	English version	Polish version
	Neutral situation cue	Recall the last time you *washed your hair.*	Przypomnij sobie jak ostatnio *myłaś głowę.*

5.4. Example sheet of the assessment form for rating memories

First page of the assessment had printed the following instructions for the task:

"*Proszę, aby Pani oceniła każdą ze swoich historii na 7-punktowych skalach. Pierwsze dotyczą tego, na ile dane wspomnienie wywołuje w Pani radość, zaskoczenie, smutek, złość, obrzydzenie lub strach.* ***1 oznacza zupełny brak odczuwania emocji, a 7 oznacza najwyższą intensywność emocji.*** *Kolejna skala („Nastrój") dotyczy tego, czy myśląc o jakimś wspomnieniu czuje się Pani zupełnie smutna/negatywnie (lewy koniec skali) lub zupełnie radosna/pozytywnie (prawy koniec skali). Ostatnia skala dotyczy pobudzenia, jakie może w Pani wywoływać wspomnienie – zupełny spokój (lewy koniec skali) lub duży niepokój/pobudzenie (prawy koniec skali). Nie ma odpowiedzi dobrych lub złych. Proszę odpowiadać zgodnie z własnymi odczuciami. Proszę otoczyć kółkiem swoje odpowiedzi.*"

English version of the instruction:

"*Please, rate each of your stories on 7-point scales. The first scales concern to what extent a given memory evokes in you joy, surprise, sadness, anger, disgust or fear.* ***1 means absolute lack of feeling an emotion, and 7 means the highest intensity of an emotion.*** *The next scale ("Mood") concerns whether you feel completely sad/negative (left end of the scale) or completely happy/positive (right end of the scale) when you think about a memory. The last scale concerns the arousal that memory may evoke in you - complete peace (left end of the scale) or high restlessness/arousal (right end of the scale). There are no right or wrong answers. Please answer according to your own feelings. Please circle your answers.*"

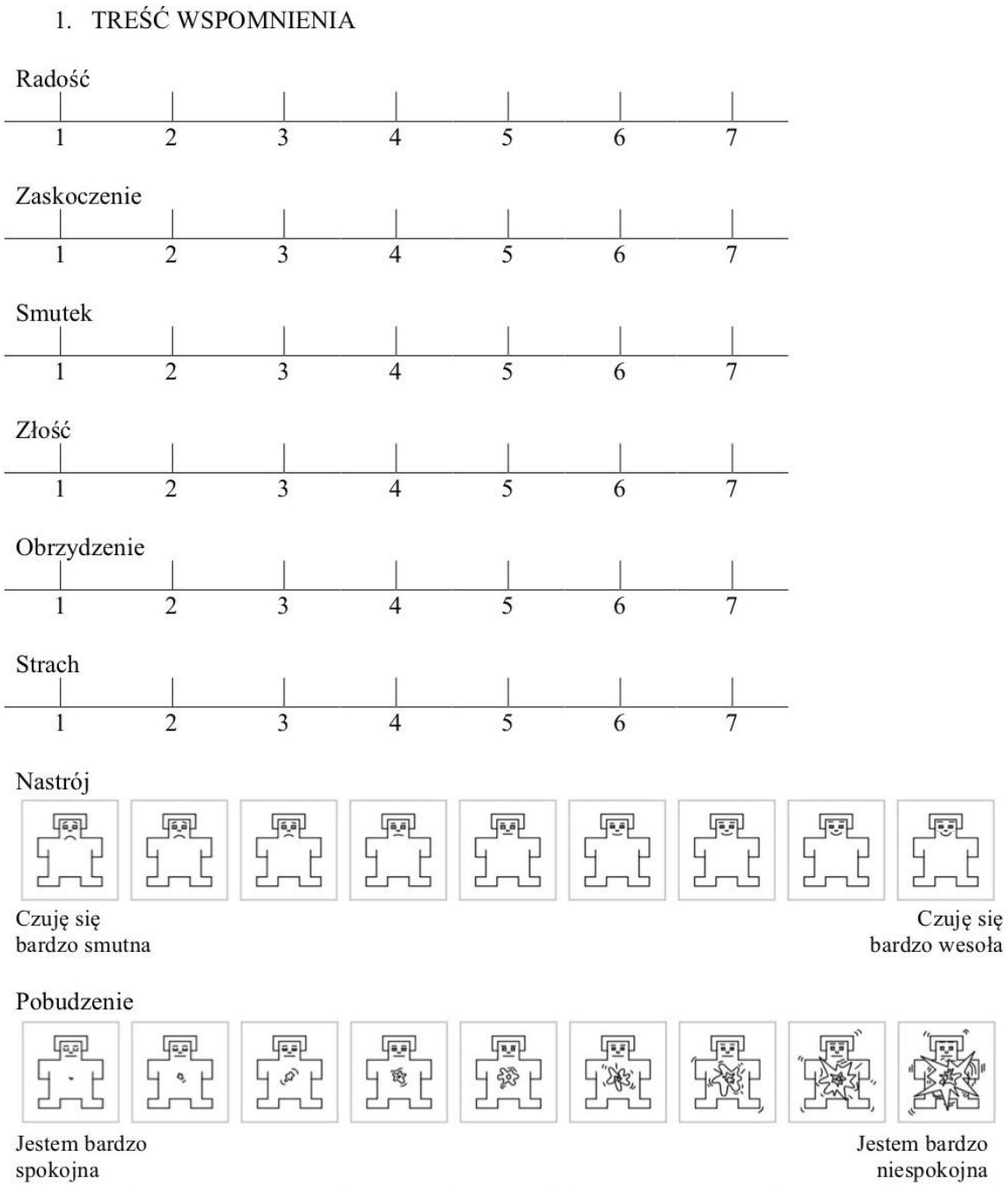

Figure S1. Example sheet of memory assessment. Participants rated all their memories on the same scales. Memories were provided in their full descriptions. The words on the sheet can be translated to: Treść wspomnienia - Memory description; Radość - Happiness; Zaskoczenie - Surprise; Smutek - Sadness; Złość - Anger; Obrzydzenie - Disgust; Strach - Fear; Nastrój - Valence/Mood; Czuję się bardzo smutna - I feel very sad; Czuję się bardzo radosna - I feel very happy; Pobudzenie - Arousal; Jestem bardzo spokojna - I am very calm; Jestem bardzo niespokojna - I am very aroused/restless.

5.5. Ratings of autobiographical memories by independent judges

5.5.1. Methods

In this part of the study 9 women participated as independent judges. All were in their late twenties and had higher education. They were asked to rate only sad and happy memories - together 1100 memories from all the participants. The AMs were randomly divided into three groups (A, B, and C) and each group was rated by 3 of the judges. The judges were informed that the memories were gathered from women over 18 years old as part of a doctoral project but were blinded to the fact that some of the participants had clinical diagnoses. They were instructed to think what level of sadness/happiness, arousal, and valence these memories trigger in the person to whom they belong, when this person recalls a given memory. Some aspects of the memories were anonymized to protect participants identity, for example, a city's name was changed or erased. Each memory was rated on three scales:

1) sadness (for sad AMs) or happiness (for happy AMs) on a 7-point Likert scale, where 1 indicated lack of sadness (happiness), and 7 indicated the highest intensity of sadness (happiness),

2) valence on a 9-point Self-Assessment Manikin scale, where 1 meant that a memory elicited very negative emotions, and 9 meant that a memory elicited very positive emotions,

3) arousal on a 9-point Self-Assessment Manikin scale, where 1 meant that a memory elicited a sense of calmness, and 9 meant that a memory elicited very high emotional arousal.

The AMs ratings of participants, who were excluded in the main study due to taking medication or due to damaged data files, were excluded from the analyses. In the end, ratings of 820 memories were analyzed.

In order to analyze reliability of judges' ratings Intraclass Correlation Coefficients (ICC; Koo and Li, 2016) estimates and their 95% confidence intervals were calculated. The ICC were calculated for each group of judges separately using a mean-rating (k = 3), absolute-agreement, 2-way mixed-effects models.

Analysis was performed using 3 statistical models with aligned rank transform for nonparametric factorial ANOVA (Fawcett and Salter, 1984; Wobbrock et al., 2011). In order to compare participant groups on how sad the sad AMs were, a 3x1 model was used with group (MDD, BPD, HC) as a between-subject variable, and with sad memories as a within-subject variable. The same comparison was performed for the happy AMs. To compare groups and memories on valence and arousal scales, two 3x2 models were used with group (MDD, BPD, HC) as a between-subject variable, and with condition (sad and happy memories) as a within-

subject variable. Post hoc tests were corrected using Holm's correction for multiple comparisons. Described analysis was performed in R Studio (RStudio Team, 2019, http://www.rstudio.com/), with the use of *ARTool* (Wobbrock et al., 2011; Kay et al., 2021), *emmeans* (Lenth, 2019), and *irr* packages (Gamer et al., 2019).

5.5.2. Results

The ICC analysis showed good reliability within all 3 groups of judges, which means that their answers were well related to each other (Table S4).

Table S4. Reliability estimates for independent judges' AMs ratings. ICC - Intraclass Correlation Coefficients; CI – confidence interval.

Group of judges	ICC	95% CI
A	0.79	0.65 - 0.86
B	0.83	0.81 - 0.85
C	0.87	0.78 - 0.91

Concerning the analyses of judges' ratings, the analysis of sadness ratings did not reveal any significant results. The analysis of happiness ratings revealed a significant main effect of group ($F(2, 79) = 3.28$, $p = 0.04$, $\eta 2 = 0.08$). Post hoc comparisons were found to be statistically insignificant.

The analysis of valence ratings revealed a significant main effect of group ($F(2, 79) = 4.64$, $p < 0.05$, $\eta 2 = 0.11$) and of condition ($F(1, 79) = 399.69$, $p < 0.001$, $\eta 2 = 0.83$), but no significant effect of interaction between group and condition ($F(2, 79) = 0.65$, $p = 0.5$, $\eta 2 = 0.02$). Post hoc comparisons of the main effect of group showed a significantly lower valence ratings of the BPD group's AMs than those of the HC group ($T = -2.78$, $p = 0.02$), but no significant differences between the valence ratings of MDD and HC groups' AMs ($T = 2.26$, $p = 0.054$). The comparison between BPD and MDD groups was not statistically significant ($T = -0.8$, $p = 0.43$). Post hoc comparison of the main effect of condition showed that happy AMs had significantly higher valence ratings than the sad AMs ($T = 19.37$, $p < 0.001$) (Figure S2).

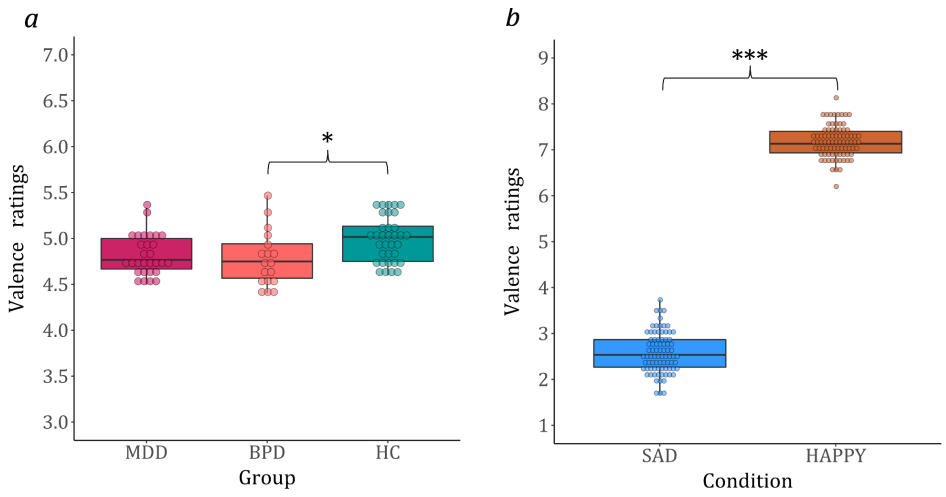

Figure S2. Behavioral results of judges' valence ratings. (a) Main effect of group. (b) Main effect of condition. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. *$p < 0.05$, ***$p < 0.001$

The analysis of arousal ratings revealed a significant main effect of condition ($F(1, 79) = 135.38$, $p < 0.001$, $\eta 2 = 0.63$), but no significant main effect of group ($F(2, 79) = 1.99$, $p = 0.1$, $\eta 2 = 0.05$) and no significant interaction between group and condition ($F(2, 79) = 1.7$, $p = 0.2$, $\eta 2 = 0.04$). Post hoc comparison of the main effect of condition revealed a significantly lower arousal ratings for happy AMs than for sad ones ($T = -11.2$, $p < 0.001$) (Figure S3).

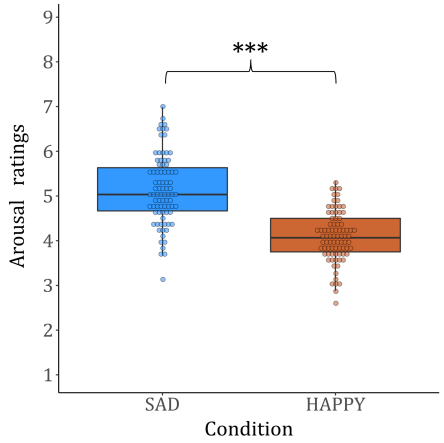

Figure S3. Behavioral results of judges' arousal ratings - main effect of condition. Dots represent individual participants. The lower and upper borders of the box correspond to the first and third quartiles, respectively. The lower and upper whiskers represent the smallest and largest data points, respectively, no further than 1.5 x interquartile range from the borders. ***$p < 0.001$

5.6. fMRI results of a comparison of $VIEW_{SAD}$ conditions between the runs in the emotion regulation task

The analysis comparing $VIEW_{SAD}$ conditions between both runs revealed that during $VIEW_{SAD}$ in MA run there were significantly greater activations than in $VIEW_{SAD}$ in CR run within the occipital and temporal gyri, and in precuneus (p < 0.001, FWEc corrected with cluster-level extent threshold of p < 0.05 and cluster size of k = 139 voxels, Table S5 and Figure S4).

Table S5. Brain activations for the comparison of $VIEW_{SAD}$ conditions between the runs. Significant p values are written in bold. The results were thresholded at voxel-wise height threshold of p < 0.001 (uncorrected) combined with a cluster-level extent-threshold of p < 0.05 and cluster size of k = 139 voxels and corrected with FWE rate. Table shows local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; L - left; R - right; MA - mindful acceptance; CR - cognitive reappraisal.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
$VIEW_{SAD}$ in MA run > $VIEW_{SAD}$ in CR run								
Middle occipital gyrus	R	139	5.48	44	-78	8	**0.03**	**0.01**
Superior occipital gyrus	R	236	5.07	28	-70	42	0.003	**0.06**
Precuneus	R		4.06	10	-72	56		**0.76**
Inferior occipital gyrus	L	526	4.66	-42	-76	-4	**< 0.001**	**0.21**
Inferior temporal gyrus	R	169	4.26	48	-70	-8	0.02	0.55
$VIEW_{SAD}$ in CR run > $VIEW_{SAD}$ in MA run								
No suprathreshold clusters								

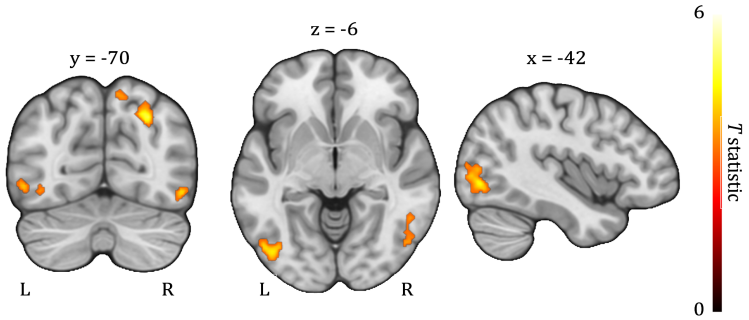

Figure S4. Whole-brain statistical parametric maps representing brain activation during $VIEW_{SAD}$ in the MA run in comparison to the $VIEW_{SAD}$ in the CR run. The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 139 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.

The $VIEW_{SAD}$ condition in the CR run showed no significant differences from the $VIEW_{SAD}$ condition in the MA run.

5.7. fMRI results of an interaction between group and ER strategies

The analysis of interaction between group and ER strategies revealed a significantly higher activation in one cluster comprised of the right angular gyrus, supramarginal gyrus, and inferior parietal gyrus. Post hoc comparisons did not reveal significant differences.

Table S6. Brain activation for an interaction between group and ER strategies. The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 169 voxels and corrected with FWE rate. Table shows 3 local maxima of each cluster separated by a minimum of 8mm. MNI - Montreal Neurological Institute; AMs - autobiographical memories; L - left; R - right.

Brain region	Hemisphere	Cluster size	*F*-value	MNI coordinates			*p* FWE cluster-level	*p* FWE peak-level
				x	y	z		
Interaction between group and ER strategy								
Angular gyrus	R	169	20.05	60	-50	36	**0.002**	**0.01**
Supramarginal gyrus	R		10.51	64	-38	38		0.95
Inferior parietal gyrus	R		10.49	60	-40	46		0.95

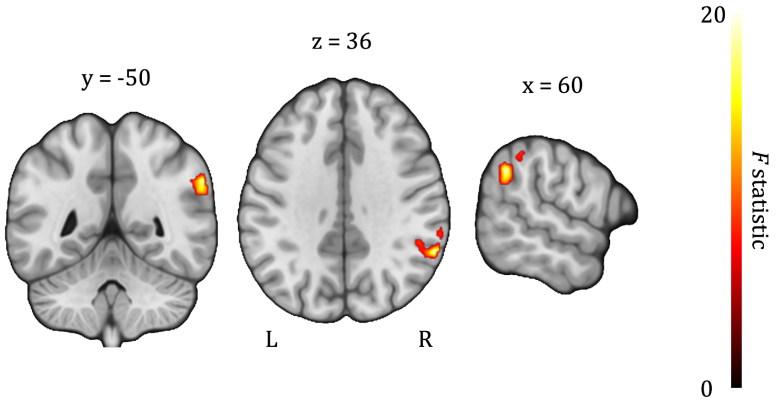

Figure S5. Whole-brain statistical parametric maps representing brain activation for an interaction between group and ER strategies. The results were thresholded at voxel-wise height threshold of $p < 0.001$ (uncorrected) combined with a cluster-level extent-threshold of $p < 0.05$ and cluster size of k = 169 voxels and corrected with FWE rate. L - left hemisphere; R - right hemisphere.