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The comparison of hot and cold executive functions in patients with bipolar II disorder, borderline personality disorder, and healthy individuals

Ayyub Sabbah, MA[a], Shekoofeh Mottaghi, PhD[b,*], Parviz Ghaedi, MA[a], Melika Ghalandari, MA[c]

Background: Differential diagnosis of bipolar II disorder (BD-II) and borderline personality disorder (BPD) has always been challenging for clinicians due to symptoms' overlap. This study aimed to compare hot and cold executive functions (EFs) in BD-II patients, as well as BPD and healthy controls (HCs), in order to differentiate these two disorders.

Methods: In the present study, 30 BD-II and 30 BPD patients undergoing the drug therapy with mood stabilizers, and 30 HC were examined using EFs evaluated tests. The data were then analyzed using ANOVA and Tukey post hoc test.

Results: The BD-II Patients performed significantly less in all cold EFs than the HC. Also, BPD patients had meaningfully lesser performance compared to HC in all cold EFs except sustained attention. No significant difference was perceived between the two patient groups in the cold EFs. In BD-II patients, the risky decision-making as a hot EFs' component was not significantly different from HC; nevertheless, its amount was significantly higher in BPD than in the HC and BD-II patients.

Conclusion: These findings underline the differences between the two mentioned disorders based on the hot EFs, which may indicate further disorder in the emotional information processing system among the BPD patients.

Keywords: bipolar II disorder, borderline personality disorder, cold executive functions, hot executive functions

Introduction

Bipolar disorder (BD) and borderline personality disorder (BPD) are considered chronic mental disorders, in which their overlapping symptoms and common comorbidity have made them difficult to be diagnosed by clinicians based on clinical interviews. However, differentiating BD-I from BPD seems relatively straightforward, reflecting the common presence of severe manic episodes, frequently with psychotic features in BD-I. However, the presence of common features, such as mood instability and impulsivity in BD-II and BPD[1], has led to the resemblance between these two disorders in terms of clinical characteristics.

So far, several studies have examined the differences between BD (especially type II BD) and BPD from psychological[2], phenomenological[3], neurophysiological aspects (Husain *et al.*)[4], and response to treatment approaches[5]. Few studies, however, evaluated and compared the two mentioned disorders based on executive functions (EFs).

HIGHLIGHTS

- Differential diagnosis of bipolar II disorder (BD-II) and borderline personality disorder (BPD) has always been challenging for clinicians due to symptoms' overlap.
- The BD-II patients performed significantly less in all cold executive functions (EFs) than the healthy control (HC).
- BPD patients had meaningfully lesser performance compared to HC in all cold EFs except sustained attention.
- Findings underline the differences between the two mentioned disorders based on the hot EFs, which may indicate further disorder in the emotional information processing system among BPD patients.

The EFs comprise top-down cognitive processes that exert control over information processing, from acquiring information to issuing a behavioural[6]. They are key functions for everyday life as well as physical and mental health, which allow the behaviour to adapt to external changes[7]. The EFs can be divided into two different categories: cold (i.e. purely cognitive) and hot (i.e. related to rewards or emotions) EFs[8]. Cold EFs involve goal achievement and problem-solving, including working memory, attentional control, cognitive flexibility, inhibition, planning, organization, and so on. While the hot EFs include the functions focusing on the role of emotional processes in cognitive control, such as self-reinforcement, empathy, theory of mind, social judgement, emotional self-regulation, ability to delay rewards, decision-making with affective components[9], and what is measured in the BART test (risky decision-making)[10].

So far, various studies have compared the patients with BD-II and BPD with healthy controls (HCs) in terms of EFs. The results

[a]Department of Counseling, Faculty of Humanities and Social Sciences, Ardakan University, Ardakan. Iran, [b]Department of Psychology, Faculty of Humanities and Social Sciences, Ardakan University, Ardakan. Iran and [c]Department of Neuroscience, Faculty of graduate school, Bahcesehir University, Istanbul, Turkey

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*Corresponding author. Address: Shekoofeh Mottaghi, Department of Psychology, Faculty of Humanities and Social Sciences, Ardakan, Iran Tel.: +989 305 043 228. E-mail: mottaghi@ardakan.ac.ir, dr.mottaghi.sh@gmail.com (S. Mottaghi).

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of some inquiries showed that the patients with BD-II had lower performance in hot and cold EFs compared to the HCs. A meta-analysis carried out by Cotrena *et al.*[11] indicated that the patients with BD-I, had moderate to severe disorders compared to the HC, while, those with BD-II had mild to moderate disorders in all cognitive functions (including inhibition, working memory, verbal fluency, cognitive alteration/flexibility, episodic memory, and planning). In addition, the results of the meta-analysis implemented by Mann-Wrobel *et al.*[12] showed that the functions such as sustained attention, response inhibition, planning, and cognitive flexibility were impaired in patients with BD-II compared to the HC. However, other studies reported that there was no significant difference between the patients with BD (types I, II) and HC in terms of the tendency to risky behaviours and risky decision-making as a hot component of EFs[13,14].

On the other hand, the results of a meta-analysis conducted by Ruocco (2005) showed that the patients with BPD had lower performance than the HC in a wide range of EFs, including cognitive flexibility, response inhibition, planning, and problem-solving, working memory, and sustained attention, which was the biggest shortcoming in the planning subset[15]. Haaland & Landrø (2007) evaluated the risky decision-making in patients with BPD and HC. The results showed that the patients with BPD had fewer useful choices (more rhazardous ones) in the Iowa Gambling Test than the HC, indicating the risky decision-making in these patients[16].

A review of the evidence illustrates that most studies conducted on hot and cold EFs compared the patients with BD-II and BPD with healthy individuals. However, few studies have evaluated and compared the aforementioned two disorders based on the hot and cold components of EFs. Hence, the question arises is whether the hot and cold EFs differ in patients with BD-II and BPD. Consequently, the purpose of the present study was to compare the cold (cognitive flexibility, response inhibition, sustained attention) and hot (risky decision-making) EFs in patients with BD-II and BPD to be able to differentiate these two disorders.

The necessity of doing research

The necessity of conducting this study lies in the challenges faced by clinicians in differentiating between BD-II and BPD due to the overlap in symptoms and clinical characteristics. Accurate diagnosis is essential for appropriate treatment planning and interventions tailored to the specific needs of individuals with these disorders. Therefore, there was a need to investigate the differences in executive functions (EFs) between BD-II and BPD, as EFs play a crucial role in cognitive control, emotional regulation, and daily functioning.

By examining and comparing the EFs of individuals with BD-II, BPD, and healthy controls, this study aimed to contribute to the existing literature on the differentiation of these disorders. Previous research has primarily focused on psychological, phenomenological, and neurophysiological aspects and response to treatment approaches. However, studies were lacking specifically exploring EFs in BD-II and BPD.

Understanding the distinct cognitive profiles of BD-II and BPD is crucial for accurate diagnosis and effective treatment planning. Identifying specific EF deficits associated with each disorder can help clinicians differentiate between them and develop targeted interventions. By investigating cold EFs (e.g. working memory, attentional control) and hot EFs (e.g. emotional self-regulation, decision-making with affective components), this study aimed to comprehensively understand the cognitive mechanisms underlying BD-II and BPD.

In summary, the necessity of conducting this study was driven by the challenges faced in differentiating BD-II and BPD, the lack of specific research on EFs in these disorders, and the need for accurate diagnosis and targeted interventions. By addressing these gaps, the study aimed to enhance the understanding of BD-II and BPD, inform clinical practice, and improve the overall treatment outcomes for individuals with these disorders.

The novelty of this study

The findings of this study contribute to the existing literature on the differentiation of BD-II and BPD by examining the differences in hot and cold EFs between these two disorders.

Firstly, this study adds to the body of literature by highlighting the differences in cold EFs between BD-II patients, BPD patients, and healthy controls (HC). The results demonstrate that BD-II patients had significantly lower performance in all cold EFs compared to HC. Additionally, BPD patients showed significantly lower performance in all cold EFs except sustained attention compared to HC. These findings suggest that impairments in cognitive aspects of executive functioning may be more pronounced in BD-II patients compared to BPD patients, providing valuable insights into the distinctive cognitive profiles of these disorders.

Secondly, the study contributes to the literature by examining the differences in hot EFs between BD-II and BPD. The results indicate that risky decision-making, as a component of hot EFs, was significantly higher in BPD patients compared to both HC and BD-II patients. This suggests that BPD patients may exhibit difficulties in emotional information processing and decision-making with affective components. These findings highlight the potential role of hot EFs in differentiating between BD-II and BPD, providing a novel perspective on the cognitive mechanisms underlying these disorders.

Furthermore, this study adds to the literature by comparing and contrasting the cold and hot EFs between BD-II and BPD. By investigating both cognitive and emotional aspects of executive functioning, the study provides a more comprehensive understanding of the cognitive profiles of these disorders. The findings suggest that while cold EF impairments may be more prominent in BD-II, hot EF impairments may be more characteristic of BPD. This contributes to the existing literature by elucidating the specific cognitive domains that differentiate BD-II and BPD.

Overall, the findings of this study contribute to the existing literature by providing empirical evidence on the differentiation of BD-II and BPD based on hot and cold EFs. By highlighting the distinct cognitive profiles of these disorders, the study enhances our understanding of their underlying mechanisms and may inform more accurate diagnostic and treatment approaches in clinical practice.

Methods

The present study is a causal-comparative research. The statistical population included all BD-II and BPD patients (male and female) with the age of 18–40 and having at least primary education who were referred to Psychiatric Department of Al-Zahra Hospital, Isfahan, during the years 2020–2021, and were diagnosed with BD-II or BPD by a psychiatrist based on the DSM-5 criteria and semi-structured SCID-5 interviews.

The statistical population of the healthy individuals included all out-of-hospital persons (male and female) with the age of 18–40, having at least primary education, who were evaluated based on a general health questionnaire and had no history of psychiatric illness, neither themselves nor their first-degree relatives. To select the samples, the members of three groups (BD-II, BPD, and HC) were first matched using a demographic questionnaire (based on age, gender, education, and marital status). Then, 30 BD-II patients, 30 BPD patients undergoing drug therapy with mood stabilizers, as well as 30 HC were selected using the convenience sampling method.

The common inclusion criterion for the BD-II and BPD groups was the application of the mood stabilizers. On the other hand, the inclusion criteria for the HC group were having no history of psychiatric illness in either themselves or first-degree relatives and not being psychiatric drug user.

The common inclusion criteria assigned for the three major study groups were as follows:

Having written informed consent to participate in the tests, being at least 18 and at most 40 years old, being literate (having at least primary education), having a normal vision and lack of colour blindness due to the visual nature of EFs evaluation tests, having no history of using or addicting to drugs (because studies have shown that chronic drug use causes the prefrontal cortex damage that underlies EFs[17], lack of serious physical and neurological diseases, and lack of suffering from epilepsy since this disease is effective in executive dysfunction[18].

The exclusion criteria for all three groups included unwillingness to cooperate and lack of accuracy and attention to respond and complete all tests.

The work has been reported in line with the STROCSS criteria[19].

The tools used in this study are as follows

Researcher-made demographic questionnaire

The researcher-made questionnaire includes basic demographic information such as age, sex, marital status, level of education, history of substance use, history of hospitalization, history of shock, length of time since receiving a psychiatric diagnosis, and use of recent medications. It also includes a brief history of neurobiological conditions (such as head trauma, epilepsy, etc.). This questionnaire was designed for initial screening and to control the inclusion criteria of the present study. In the present study, cognitive flexibility, response inhibition, and sustained attention were evaluated as the cold components of EFs using the Simple Strop, Go/No Go, and Continuous Performance Test (CPT), respectively, and the risky decision-making was examined as a hot component of EFs using Balloon Analog Risk Task (BART) test among all participants.

Simple strop task

This test was first developed by Stroop (1935) to measure selective attention and cognitive flexibility. The Simple Stroop test, which has acceptable reliability and validity in neuropsychological studies, is used to measure selective attention ability through a visual method. In this test, 48 matched colour words and 48 mismatched ones are displayed in red, blue, yellow, and green. The phrase "matching words" means that the colour of each word matches its meaning; for example, "the word green is shown in green." On the other hand, mismatched words mean that the colour of each word differs from the meaning of the word. For example, "the word green is presented in red, blue, or yellow." The 96 matched and mismatched colour words are displayed randomly and sequentially. The examinee's task is to determine only the apparent colour of the words, regardless of their meaning. The reliability of 0.80–0.91 has been reported for the Stroop test through test-retest, which is high and acceptable. In the current study, the number of correct responses scores given to mismatched words on this test was considered to measure cognitive flexibility[20].

Go/no go task

This test, which its first version was designed by Hoffman in 1984, is widely used by researchers to measure behavioural inhibition[21]. In this test, the pairs' number of white/green, white/yellow rectangles randomly appears on a computer screen for a short time, and the subject must pay attention to these pairs of stimuli. If a pair of rectangles that the participant sees is yellow, he/she should not give any answer, but if one pair of rectangles is green, he will give one of the two following answers depending on whether the green rectangle is left or right. In case the green colour is on the right hand and the white colour is on the left side of the screen, the examinee must push the button specified on the right side of the keyboard (? button) with maximum speed. Meanwhile, if the white colour is on the right and the green colour is on the left side of the screen, the examinee must push the button marked on the left side of the keyboard (Z button) at maximum speed. In our study, the total number of stimuli in this test was 40, and each of them was manifested for 0.2–3 seconds. The interval between the two presentations of the two stimuli was one second. In all cases, the "go" stimuli constitute 75% of the total stimuli. Therefore, the examinee's bias is towards the "go" answer. The validity of this test has been reported to measure appropriate response inhibition, and its reliability was obtained at 0/87 in the research carried out[22,23]. The Response inhibition score or loss of correct answer (no answer to go) was used to measure the response inhibition in the present study.

Continuous performance task (CPT)

This test is one of the most important tools for measuring sustained attention, and its purpose is to examine attention retention, care, alertness, and focused attention. This test includes 150 stimuli, of which 30 stimuli include the target stimulus ,the distance between the two stimuli is 500 thousandths of a second, and the presentation time of the two stimuli is 150 milliseconds. In this test, the examinee should pay attention to a set of stimuli for a while and give his/her answer when the target stimulus appears by pushing a key. In the study of Hadianfard and colleagues the validity of this test was confirmed for measuring stable attention, and also the reliability coefficient of the test's different parts was obtained between 0.53 and 0.93. The score of the correct answers on this test was used to measure the sustained attention in the present study[24].

Balloon Analog Risk Task (BART)

This test was first introduced by Lejuez and colleagues and examines a person's risk-taking in real conditions. In this test, the image of a balloon appears on the computer screen, and the person can inflate it by pushing the button below it. Each time the examinee inflates the balloon, he/she gains more points; however, the balloon may burst somewhere, which in that case, he/she loses all achieved points. In this test, the adjusted score (average frequency of inflating balloons without explosion), the test's main score, and the risk-taking indicator are examined[10]. Many studies have pinpointed the validity of this test. In addition, Cronbach's alpha of this test has been reported to be 0.79, which is appropriate[25].

Statistical analysis

The data were analyzed using SPSS software version 25. Three groups were compared based on demographic variables using χ^2 test. The data on hot and cold EFs of the three groups were distributed using the Kolmogorov–Smirnov test. Then, descriptive statistics (mean and standard deviation), inferential statistics (ANOVA), and Tukey post hoc tests were carried out in the mentioned three groups.

Results

In the present study, 30 BD-II patients, 30 BPD patients and 30 HC were examined. Table 1 briefly indicates the demographic characteristics of the three groups. The data analysis showed no significant differences in demographic variables among the three groups (all $P > 0.05$; $P > 0.01$). In order to use the ANOVA, the variances' homogeneity of the Hot and cold EFs were studied among the three groups through Leven test. The results of this test exhibited that there are no significant differences among the three groups in terms of cold and hot EFs' variances (all $P > 0.05$; $P > 0.01$). Therefore, due to the homogeneity of the variances, the ANOVA was used. The evaluation results of cold and hot EFs among the three groups are presented in Table 2.

As can be seen in Table 2, there is a statistically significant difference among the mean scores of the three groups in terms of cognitive flexibility ($F = 10.23$, $P < 0.01$), response inhibition ($F = 8.94$, $P < 0.01$), sustained attention ($F = 9.26$, $P < 0.01$) and risky decision-making ($F = 5.53$, $P < 0.01$). To evaluate the difference among the mean of the three groups in hot and cold EFs, the Tukey post hoc test was used, and which the findings are presented in Table 3.

The results of the Tukey test presented in Table 3 demonstrate that patients with BD-II and BPD performed significantly lower in terms of cognitive flexibility and response inhibition than those with HC. Nonetheless, no significant difference was observed between two groups of patients in terms of cognitive flexibility and response inhibition. In addition, patients with BD-II performed at a lower level in terms of sustained attention than patients with HC. However, there was no significant difference between the patients' performance with BPD, HC and BD-II in terms of sustained attention. The results also showed that the risky decision-making in BD-II patients was not significantly different from the HC, but it was meaningfully higher in BPD patients compared to HC and BD-II patients.

Table 1

Demographic characteristics of patients with BD-II, BPD and HC

Variables	BD-II ($n = 30$), n (%)	BPD ($n = 30$), n (%)	HC ($n = 30$), n (%)	χ^2	P
Education				16.69	0.125
Elementary	0	3 (10)	2 (6.7)		
First high school	1 (3.3)	5 (16.7)	2 (6.7)		
Secondary high school	4 (13.3)	5 (16.7)	3 (10)		
Diploma	21 (70)	7 (23.3)	15 (50)		
Associate degree	1 (3.3)	3 (10)	5 (16.7)		
Bachelor's degree	3 (10)	5 (16.7)	2 (6.7)		
Master's degree	0	2 (6.7)	1 (3.3)		
PhD	0	0	0		
Age				20.87	0.126
18–25 years	11 (36.7)	17 (56.7)	14 (46.7)		
26–32 years	3 (10)	6 (20)	5 (16.7)		
33–40 years	16 (53.3)	7 (23)	11 (36.7)		
Sex				0.62	0.441
Male	15 (50)	17 (56.7)	16 (53.3)		
Female	15 (50)	13 (43.3)	14 (46.7)		
Marital status				0.49	0.131
Single	10 (33.3)	15 (50)	10 (33.3)		
Married	20 (66.7)	15 (50)	20 (66.7)		

BD-II, bipolar II disorder; BPD, borderline personality disorder; HC, healthy control.

Discussion

The aim of this study was to compare cold (cognitive flexibility, response inhibition, and sustained attention) and hot (risky decision-making) EFs in patients with BD-II, BPD and HC. According to the findings, as expected, the BD-II and BPD patients performed lower in cold EFs than the HC. The patients with BD-II had significantly lower performance in terms of cognitive flexibility, response inhibition, and sustained attention compared to the HC. Consistent with these findings, the results of the meta-analysis performed by Cotrena *et al.*[11] showed that BD-II patients had disorders in many EFs, including cognitive alteration/flexibility and response inhibition, compared with the HC. In addition, Mann-Wrobel *et al.*[12], in their meta-analysis, discovered that the EFs such as cognitive flexibility, response inhibition, and sustained attention were not functioning well in BD-II patients compared with the HC.

In the present study, it was revealed that the cognitive flexibility and response inhibition abilities were significantly lower in the patients with BPD compared to the HC. However, in terms of sustained attention, the difference was not significant, even though the patients with BPD received lower scores for this component than the HC. This is partly consistent with the results of Ruocco (2005), inquiry, suggesting that the patients with BPD had lower performance in cognitive flexibility, response inhibition, and sustained attention in comparison with the HC. However, the difference in sustained attention was not significant in the present study, which is in contrast with Ruocco's findings[15].

What is extraordinary in explaining these findings is the impaired prefrontal cortex (PFC) function in patients with BD-II and BPD. The PFC is traditionally associated with EFs, and any damage to these areas is reflected by defects in EFs. According to previous studies, cold EFs with less emotional salience often

Table 2

The results of hot and cold EFs' evaluation in patients with BD-II, BPD, and HC

	Mean ± SD			Test	
EFs	BD-II	BPD	HC	F	P
Cold					
Cognitive flexibility	34.10 ± 15.53	37.03 ± 12.81	47.07 ± 1.01	10.23	0.000
Response inhibition	28.30 ± 8.57	30.37 ± 9.51	37.16 ± 7.25	8.94	0.000
Sustained attention	142.40 ± 7.97	145.97 ± 6.89	149.20 ± 1.19	9.26	0.000
Hot					
Risky decision-making	41.37 ± 17.41	51.47 ± 16.04	39.20 ± 11.72	5.53	0.005

BD-II, bipolar II disorder; BPD, borderline personality disorder; EF, executive function; HC, healthy control.

activate the dorsolateral prefrontal cortex (DLPFC)[25]. Although the PFC plays a very effective role in EFs, other areas of the brain, including the anterior and posterior cingulate cortex, are also strongly involved in EFs[9].

Functional MRI (fMRI) studies of HCs, examining emotions' cognitive regulation, underline the increased activation of medial and lateral prefrontal cortices and decreased activation of the amygdala and internal orbitofrontal cortex (OFC). This supports the hypothesis that the PFC and its association with limbic structures provide reassessment strategies that can modulate activities in multiple emotion-processing systems. Considering the central role of prefrontal areas and their relationship with other cortical and subcortical-limbic structures, successful emotional regulation strongly affects a wide range of cognitive domains, including attention, executive ability, and memory. The attention and EFs domain involving in emotional regulation includes working memory, inhibition, and problem-solving, planning, and cognitive flexibility[26].

However, neuroimaging studies showed abnormalities in different areas of the brain (including larger lateral ventricles, smaller Corpus Callosum, reduced ventromedial prefrontal cortex, reduced anterior cingulate cortex volume, and amygdala enlargement) in patients with BD. These studies also reported decreased amygdala volume, reduced hippocampal volume, OFC, anterior cingulate cortex, and decreased blood flow as well as metabolism in several areas of the brain (including DLPFC and anterior cingulate cortex) in patients with BPD[27]. The low performance of the patients with BD-II and BPD in cold EFs could probably be due to the damage that occurred in the PFC and limbic structures compared to healthy individuals. Although it was found that the patients with BPD did not significantly differ from the HC in terms of sustained attention, they obtained lower scores. The relative improvement in sustained attention of these patients could perhaps be attributed to their impulsivity. Unplanned motor impulsivity and hasty actions are characteristics of BPD[26]. This type of impulsivity is likely to affect the performance of patients in the CPT test because the optimal performance in this test requires quick responses to the stimuli. On the other hand, patients' exposure to the test, their preparedness due to the implementation of the experimental stage before the main test, and also trying to show themselves better in the test process could be considered as other factors affecting their performance in the CPT test.

The results did not show a significant difference in terms of cold EFs between the patients with BD-II and BPD. It seems that there was a serious and common injury in the PFC as well as the limbic systems of both patients' groups, which led to their impaired cold EFs.

The findings also indicated that the patients with BD-II were not significantly different from the HC in terms of risky decision-making, which is known as the hot component of the EFs. This is consistent with the results of the research done by Ramírez-Martín and colleagues and Ibanez and colleagues, who found in their studies that there was no significant difference between the patients with BD (types I, II) and HC in terms of the tendency to do risky behaviours and risky decision-making[13,14].

In addition, the findings suggested that the risky decision-making in the patients with BPD was significantly higher than its amount in the HC and the patients with BD-II. Consistent with this outcome, the results of the study implemented by Sánchez-Navarro and colleagues, (2014) specified that the patients with BPD were more risk-taking in risky decision-making assessment tests than the HC. In other words, when decisions were considered as a potential loss, they sought risk, but, when the outcome involved sheer losses, the patients were not sensitive to the relative expected values of the options chosen; hence, they would make unfavourable decisions[27]. In the study accomplished by Haaland & Landrø (2007), it was uncovered that the patients with BPD had fewer useful choices (more harmful ones) in the

Table 3

Paired comparison of the hot and cold EFs' means among the patients with BD-II, BPD, and HC group using Tukey post hoc test

	Tukey post hoc test			
EFs	Group	Group	Mean difference	P
Cold				
Cognitive flexibility	BD-II	HC	− 12.96*	0.000
	BPD	HC	− 10.03*	0.004
	BD-II	BPD	− 2.93	0.594
Response inhibition	BD-II	HC	− 8.86*	0.000
	BPD	HC	− 6.80*	0.007
	BD-II	BPD	− 2.06	0.615
Sustained attention	BD-II	HC	− 6.80*	0.000
	BPD	HC	− 3.23	0.107
	BD-II	BPD	− 3.56	0.067
Hot				
Risky decision-making	BD-II	HC	2.17	0.847
	BPD	HC	12.27*	0.007
	BD-II	BPD	− 10.10**	0.032

*$P > 0.01$.

**$P > 0.05$.

BD-II, bipolar II disorder; BPD, borderline personality disorder; EF, executive function; HC, healthy control.

Iowa Gambling Test than the HC, showing the risky decision-making in these patients[16].

However, on the contrary to the findings of the present research, Abolalaei *et al.*[28] found that the patients with BD (types I, and II) had higher mean scores in risky decision-making than the patients with BPD.

To clarify on these findings, it could be said that according to studies, hot EFs often activate the brain areas that control emotions and reward systems in the brain (e.g. OFC, corpus striatum ventral, and limbic system)[29]. It appears that three nervous systems related to the stimulus encoding process (i.e. the OFC), the system of reward selection and monitoring (e.g. the cingulate cortex), and the expected reward processing (i.e. the basal ganglia and amygdala) are involved in the risky decision-making[14]. However, the findings indicated some disorders in both the amygdala and the OFC areas in patients with BPD (Haaland & Landrø, 2007)[16]. The tendency to make risky decisions by the patients with BPD was probably due to a disorder in the information processing system related to rewards and emotions in these patients.

Furthermore, Berlin and colleagues believed that patients with BPD might not respond to amplifiers. This phenomenon is possibly related to the amygdala system, which could lead to patients' indifference to behavioural outcomes and, consequently, risky behaviours. However, this might not be the case in patients with BD-II, as they could respond more to amplifiers. On the other hand, as mentioned earlier, unplanned motor impulsivity and hasty actions are among the characteristics of BPD without considering the consequences[30].

Although impulsivity is observed in patients with BD, attention impulsivity often includes a wide range of internal cognitive processes such as attention and concentration reduction, distraction, and competitive thinking[26]. The nature of impulsivity seems to be different in patients with BPD and those with BD, which may affect the tendency of these patients to take risky behaviours and make risky decisions.

In addition, the risky decision-making in patients with BD may be influenced by mood swings in depression and manic episodes in these patients (Martino *et al.*)[31] or, as suggested by Ernst and colleagues, the risky decision-making in patients with BD might appear only in a state of insanity. Thus, decision-making disorders (risky decision-making) in patients with BD might be more indicative of mood than trait[32]. However, all the patients with BD-II in the present study were in the euthymic phase as well as treatment with drugs and mood stabilizers, which could possibly prevent them from making risky decisions.

Strengths and limitations

Although attempts were made to apply scientific principles in all stages to obtain reliable results, like most neuroscience studies, the present research had some limitations. Thus, some limitations of this study could be emphasized, such as the following: Firstly, the prevalence of COVID-19 disrupted the research process. Secondly, the patients sample groups of this study were only taken from one hospital. Therefore, it is suggested to select patients' samples from a variety of hospitals for better generalization of the results. Thirdly, the present study only focused on the functions of cognitive flexibility, response inhibition, sustained attention, and risky decision-making in patients with BD-II, BPD, and HC. Therefore, considering the extent of cold and hot components of EFs, it is proposed that other cold and hot components of the EFs be evaluated and compared in these three groups. Finally, the computer software developed by Sina Institute was used to measure attention functions. However, the use of other advanced neuroscience tools is recommended to examine more closely the structural and functional similarities and differences between the BD-II and BPD patients' brains.

Conclusion

In general, based on the findings of the present study, it can be noted that patients with BD-II and BPD are suffering from severe defects in cold EFs, possibly due to the injury in their PFC and also in some limbic structures. This makes it difficult to differentiate the two disorders based on the cold EFs. However, patients with BPD appear to have greater extensive defects in the brain reward's information processing system than those with BD-II. Unlike the patients with BD-II, the BPD patients have difficulty assessing the profits and losses. Instead, they prefer short-term and immediate rewards regardless of the long-term consequences of their decisions and, as a result, seek more risky situations. Hence, differentiation of the two disorders based on the hot EFs, especially risky decision-making, seems promising, even though proving these findings requires neurological imaging using advanced imaging tools.

Future research directions

Firstly, future studies could explore the relationship between specific EFs and symptom severity in BD-II and BPD. By examining how different EFs are associated with the severity of mood instability, impulsivity, and other core symptoms of these disorders, researchers can identify potential cognitive markers that may aid in diagnosis and treatment planning. Furthermore, investigating whether certain EF deficits are linked to specific symptom profiles within BD-II and BPD subgroups could provide valuable insights into the heterogeneity of these disorders.

Secondly, it would be beneficial to investigate the impact of different treatment approaches on EFs in BD-II and BPD. Exploring how pharmacological interventions, psychotherapy, or a combination of both affect executive functioning can help determine the most effective treatment strategies for individuals with these disorders. Additionally, longitudinal studies tracking changes in EFs over the course of treatment can provide insights into the potential role of EFs as predictors of treatment outcomes.

Furthermore, considering the overlap between BD-II and BPD, future research could examine the potential shared underlying mechanisms of EF impairments in these disorders. Investigating common genetic, neurobiological, or cognitive factors that contribute to EF deficits in both BD-II and BPD could provide a deeper understanding of their aetiology and inform the development of targeted interventions.

Lastly, as the present study focused on cold and hot EFs, future research could explore other aspects of executive functioning that may be relevant to BD-II and BPD. For example, investigating social cognition, decision-making under uncertainty, or emotion regulation skills can provide a more comprehensive understanding of the cognitive processes involved in these disorders.

In summary, future research directions may involve examining the relationship between specific EFs and symptom severity or treatment outcomes, investigating shared underlying mechanisms, and exploring other aspects of executive functioning. These avenues of research have the potential to contribute to the development of targeted interventions and improve the diagnostic and treatment approaches for individuals with BD-II and BPD.

Ethical approval

This study was approved by the research ethics committees of vice-chancellor in research affairs -medical university of isfahan (ethical code IR.MUI.RESEARCH.REC.1399.586).

Consent

Written informed consent was obtained from the patients for publication and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

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Author contribution

All authors contributed to the design and implementation of the study.

Conflicts of interest disclosure

The author declares no conflicts of interest.

Research registration unique identifying number (UIN)

The article was cross-sectional, and no human or animal intervention was performed. In Iran, only clinical trial studies are registered, and cross-sectional or descriptive, comparative studies are exempted from registration. But the study has been approved by the Ethics Committee of Isfahan University of Medical Sciences.

Guarantor

All authors accept full responsibility for the study.

Data availability

Data are available from authors on request.

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