


Article

EEG-Correlates of Emotional Memory and Seasonal Symptoms

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Abstract: The aim of this study was to investigate a potential all-year vulnerability of people with seasonal mood fluctuations. We compared behavioral and neurophysiological responses to emotional stimuli in summer between people who report seasonal symptoms in winter and those who do not. EEG was recorded in summer from 119 participants while they memorized 60 emotional pictures, balanced for valence and arousal. The Seasonal Pattern Assessment Questionnaire was used to determine seasonal symptoms. EEG power was analyzed in the alpha and gamma frequency bands and in early (50–150 ms) and late (300–400 ms) time-windows over frontal, temporal, and occipital sites. Positive pictures were more frequently recalled than negative and neutral pictures, and negative pictures were more frequently recalled than neutral pictures ($p < 0.001$), but memory performance did not interact with seasonality. EEG power was overall higher in participants without elevated levels of seasonal symptoms ($p = 0.043$). This group difference interacted with emotional valence ($p = 0.037$), region of interest ($p = 0.003$), hemispheric differences ($p = 0.027$), frequency band (0.032), and time-window (0.018). This differential pattern of activation while viewing emotional pictures suggests a difference in emotional processing between the groups. The absence of behavioral effects but presence of differences in EEG activity suggests an all-year-long difference in processing of emotional contents in people who experience seasonal symptoms in winter.

Keywords: seasonal affective disorder; seasonality; EEG band-power; emotional memory; negativity bias



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1. Introduction

Seasonal affective disorder (SAD) was first described as recurring depressive episodes, which usually appear annually at the same time of the year [1]. SAD is classified under major depression along with bipolar I and bipolar II in the Diagnostic and Statistical Manual for Mental Disorders, 5th edition (DSM-V) [2,3]. Although more severe outcomes such as suicide are not a primary concern of SAD, affected individuals suffer significantly from the annual drop in well-being and productivity, as SAD symptoms include hypersomnia, hyperphagia (increased appetite), carbohydrate cravings, sadness, anxiety, irritability, daytime drowsiness, and work and interpersonal difficulties [1]. The fall/winter type of SAD is more common than the spring/summer type and it is assumed that decreased sunlight is the reason for that [4]. However, cultural variation relates to both types [5]. Some ethnic groups in northern latitudes might have adjusted to long winters in relation to seasonality [6]. In contrast, in tropical latitudes, humidity and heat during the summer are factors contributing to seasonality symptoms [7]. The Seasonal Pattern Assessment Questionnaire (SPAQ) was developed by Rosenthal as a screening tool for seasonal symptoms, which can aid identification of those who are likely to have SAD [8], but the questionnaire is not meant for clinical diagnoses [9]. A global seasonality score (GSS) yields from the test as a criterion of the severity of seasonal symptoms with a common cut-off for identifying SAD to be likely at a $GSS \geq 10$ [10]. However, the GSS cut-off is not necessarily an indicator for a DSM diagnosis of the disorder [8]. We refer to seasonal symptoms as identified with the GSS as seasonality hereafter.

Brain correlates of SAD have been studied to a small extent so far, but in related disorders such as depression a commonly reported finding is asymmetric activity in frontal brain areas as detected with an electroencephalogram (EEG) [11,12]. In particular, frontal alpha asymmetry is frequently reported as an EEG biomarker for depression [13–17]. In patients with depression, brain activity along the anterior–posterior axis and right lateralized resting alpha is subject to change, resulting in dysfunction of the right hemisphere [18]. However, there seems to be inconsistency between studies and several of them have fallen short in finding the effect of atypical frontal alpha asymmetry in depressed patients [18–20]. Experimental results on SAD and EEG power confirm the physiological similarity between depression and SAD; specifically, asymmetrical distribution as well as lower power for individuals with SAD was reported for most frequency bands as compared to controls [21]. In a recent study, we could demonstrate increased responsivity of the alpha frequency range to sad mood induction among individuals with seasonality symptoms even in the season where these individuals should feel better, i.e., during summer [22].

There is a plausible explanation for the frontal lobe and particularly alpha activity to be abnormal in affective disorders. Specifically, there is a link to memory and emotion, which emerges as frontal asymmetry being indicative of variability in emotional processing [23–26]. Humans have the tendency to incorporate negative information when learning how to handle situations that require cognitive abilities; the literature suggests that this negativity bias serves an evolutionary purpose [27]. While the grounds for learning from negative affect may be vital in many situations, weighing negative information heavily and dominantly over positive information is a possible indicator of mental disorder [28,29]. Emotions play a key role in memory consolidation; they induce capturing of attention and increase processing of information [30,31]. Frontal EEG alpha asymmetry might serve as a mediator for interindividual differences and disease, as it is said to reflect an individual's sensitivity to negative emotional cues [32]. Emotions also seem to be more important for top-down attention in processing stimuli that provoke a sad mood in people with depression [33–35].

In addition to the alpha band being involved in emotional processing and serving as markers for depressive disorders, gamma oscillations have been consistently reported to be linked to depression [36]. EEG research on emotional memory has led to the conclusion that affective stimuli evoke increased gamma oscillations (35–120 Hz) in the neocortex and the amygdala, particularly stimuli with negative valence [37]. Negative stimuli may undergo enhanced processing, which was suggested to be reflected by responses after 300 ms in the gamma band [38], and this enhanced processing is even more sustained in individuals with depression [39]. These results were interpreted such that neural connectivity and activation of the visual cortex enhance the ability to perceive emotional stimuli early to facilitate fast reaction to what might appear as aversive [38]. An increase in gamma-band event-related synchronization was linked to conscious experience (supraliminal priming) for emotional stimuli [40]. Another study examined event-related gamma rhythm modulation and the phase of synchronization to describe differences in emotional memory by viewing positive, negative, and neutral pictures [41]. Differences in gamma synchronization were found between neutral stimuli and negative stimuli in the gamma range of 38–45 Hz at 0–250 ms post-stimulus [41]. Neuronal activity in the gamma band is also enhanced while processing fearful-looking faces [42]. In line with these findings, an increase in gamma-band power was reported in the right frontal region for positive stimuli and in the left frontal and temporal regions for negative stimuli [43]. Most interestingly, patients with depression showed increased frontal responses to negative words in the gamma band compared to healthy controls [42].

Despite converging results on frequency bands and brain regions involved in emotional processing and depression, there is considerable inconsistency across published studies on time ranges for valence effects following presentation of emotional stimuli [44]. For instance, the greatest effects of emotional valence were reported in occipital–temporal regions at 200–350 ms post-stimulus in event-related potential [45], whereas other re-

searchers reported the greatest effect of valence at 105 ms post-stimulus in the occipital region [46]. It was, therefore, suggested that the effects of valence are mainly detectable in the time range of 100–300 ms post-stimulus [44].

While this processing bias for negative stimuli is well researched in depression, little is known about whether such a bias also exists in depression triggered by specific environmental conditions, specifically, SAD. It is possible that processing and memory of negative stimuli might be altered in SAD. However, emotional memory has been studied in relation to seasonality mainly with respect to behavioral effects. It was shown that patients with SAD demonstrate a memory bias for negative stimuli during winter [47]. Furthermore, they experience a greater reduction in performance when recalling positive pictures from summer to winter than controls [48]. Improvement in mood during summer was predicted by a greater emotional Stroop effect for negative words in the winter [49]. According to recent research on this topic [50], even though patients with winter-type SAD experience impaired memory performance and a negative emotional memory bias during the symptomatic period in winter, all-year-round research is missing on the topic of memory and SAD. It could be relevant to study emotional processing in summer for individuals at risk of SAD, as deviations from the normal pattern could indicate how they are vulnerable to experiencing depression in winter. In a functional magnetic resonance imaging experiment, it was found that individuals with SAD showed no differential reactivity to emotional faces as compared to healthy controls in either season but had overall lower activity in their amygdala [51]. Possibly, this difference represents an all-year vulnerability of patients with SAD.

However, so far, no research has examined electrophysiological correlates of emotional memory in relation to seasonal symptoms, especially not in a remission phase, i.e., in the season when individuals who experience seasonal fluctuations of mood feel relatively good. The rationale for investigating emotional memory bias as well as physiological correlates of emotional processing of stimuli during remission is that an all-year vulnerability could direct therapy approaches towards early intervention that might help to prevent depressive episodes during winter. For example, variation in emotional processing during remission could suggest that preventive interventions should aim at modification of emotional bias. The purpose of this study is to evaluate the following research questions:

Is there an emotional memory bias in summer towards negative pictures in people who report a high rate of seasonal symptoms?

Does brain activity measured by the EEG during learning of emotional pictures in summer differ according to emotional valence and the degree of seasonality?

2. Materials and Methods

2.1. Recruitment

Recruitment was conducted by advertising for participants via social media and among students at the University of Akureyri in the North of Iceland. The premise for participating was a steady and judicious state of mind to give informed consent and age of at least 18 years. Instructions and materials were in Icelandic; thus, competency in the Icelandic language was required. The study is a part of more extensive research, where participants were required to partake in self-report questionnaires online. Compensation for having partaken in the study was a 4000 ISK gift certificate.

2.2. Questionnaire

To evaluate the participants' mood and behavioral seasonal fluctuations, the SPAQ was used to estimate seasonality among participants. The test is an 8-item self-administered questionnaire, which is designed to evaluate the severity of seasonal changes in energy, mood, sociability, appetite, and sleeping, as well as seasonal factors such as weather conditions, in retrospect [52]. Psychometric properties in the Icelandic version of the instrument are characterized by a sensitivity of 94%, specificity of 73% and positive predictive value for combined groups of SAD and subsyndromal SAD (S-SAD) of 45% [53]. The English

version of the test has been indicated to have overall good psychometric properties (factor structure, score distribution, internal consistency, and test–retest reliability [8]). GSS score, age, and gender for the sample can be found in the supplementary data file.

2.3. Picture Learning Condition

We chose to use emotional pictures from the Open Affective Standardized Image Set (OASIS), which is an open-access picture bank containing 900 pictures with normative measurements of two facets: arousal and valence [54]. While the participants' brain responses were measured with the EEG, they were shown 20 negative, 20 positive, and 20 neutral pictures in a random order. Pictures of each of the three emotional categories were balanced by low, medium, high arousal ratings. Each picture was shown on a black screen for at least 2000 ms and as long as required until the participant indicated by a button press whether the picture would rather belong to spring, summer, fall, or winter. We required a response to maintain attention and ensure processing of the pictures, and to facilitate memory encoding. The inter-trial interval was 1000 ms plus a variance of 0–10 screen flip intervals. During the inter-trial interval, a white fixation cross was presented at the center of the black screen.

Afterwards, participants were asked to freely recall the pictures. Their responses were recorded manually by an experimenter and matched with the list of pictures. Counts for remembered pictures within each valence category were then used for analysis of emotional memory effects. Number of remembered images per valence category can be found in the supplementary data file.

2.4. EEG Recording and Analysis

The EEG was recorded with a passive 32-channel EEG recording system using AgAg electrodes and the software Brain Vision Recorder, both from Brain Products GmbH, Gilching/Germany. Data were digitized at a sampling rate of 1 kHz using an Easy Cap where electrodes were placed in an extended 10–20 system, including 31 electrodes for recording brain activity (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fz, Cz, Pz, FC1, FC2, CP1, CP2, FC5, FC6, CP5, CP6, FT9, FT10, TP9, TP10) with a reference at FCz and ground at AFz. An additional electrode was used to record a lower vertical electrooculogram to monitor eye movements.

We analyzed EEG data with the software Brain Vision Analyzer 2 (Brain Products GmbH, Gilching/Germany) from the picture learning condition in the following steps.

For preprocessing, common average re-referencing was performed, and data were filtered from 0.5 to 48 Hz with zero-phase-shift Butterworth filters in order to exclude line noise (50 Hz) and muscle artefacts above that range. Next, an independent component analysis (ICA) and back-transform with the infomax restricted algorithm was applied to automatically remove eye-blink artefacts. The vertical lower oculogram was used as a vertical activity channel. As a last preprocessing step, an automated raw data inspection was carried out to identify and exclude artefacts using standard thresholds as implemented in Brain Vision Analyzer:

- Check gradient: maximal allowed voltage step: 50 microvolts/ms;
- Check difference: maximal allowed difference in values in intervals of 200 ms: 200 microvolts;
- Lowest activity allowed in 100 ms intervals: 0.5 microvolts.

Bad events were marked ± 200 ms around the identified artefacts. Then, data were band-pass filtered in the alpha (8–12 Hz [26]) and gamma ranges (35–45 Hz [39]). Finally, time-averaged rectified activity was exported for two time-windows: 50–150 ms post-stimulus-onset and 300–400 ms post-stimulus-onset, separately for the two frequency bands and the three stimulus categories. Segments overlapping with bad events were excluded. The electrodes used for statistical analysis were F3, F4, F7, F8, T7, T8, O1, and O2 to cover core electrodes over the regions of interest (frontal, temporal, and occipital). This data can be found in the supplementary data file.

For the purpose of illustrating the appropriateness of the choice of the time-window and frequency range, for each picture category (negative, neutral, and positive), data were segmented from -500 ms to $+1000$ ms around stimulus presentation and submitted to a wavelet transform. We conducted wavelet analysis with Morlet complex wavelet (Morlet parameter $c = 5$) for the frequency range 1–48 Hz in 1 Hz linear frequency steps. Wavelet normalization was performed using instantaneous amplitude (Gabor normalization). We averaged the results for each picture category over the participants with elevated seasonality and low seasonality scores.

2.5. Statistics

Statistical analysis was conducted with IBM SPSS Statistics for Windows, Version 23.0 and R 4.2.1 / R-Studio 2022.02.3 [55]. Internal consistency analysis was carried out for all items on the global seasonality subscale of the SPAQ. Cronbach's alpha indicated a good reliability ($\alpha = 0.88$). Then, the global seasonality score (GSS) was calculated by summing all answer items. This seasonality grouping was utilized as a between-subjects factor in statistical tests.

For statistical analysis of EEG data, the following repeated-measures factors were used: hemisphere (left, right), frequency (alpha, gamma), time-window (50–150 ms, 300–400 ms), region (frontal, temporal, occipital), and valence (negative, positive, neutral). The seasonality grouping variable categorized participants as having low symptoms if their seasonality score was 10 or lower and high if their seasonality score was 11 or higher.

To test the overall effects according to our hypotheses, we conducted a semi-parametric repeated-measures ANOVA that allows for non-normality and variance heterogeneity [56] using the function RM from the package MANOVA.RM [57]. Significant main effects and interactions were followed up with post hoc tests that were conducted as univariate ANOVA with the same method. Bonferroni–Holm correction was applied in all instances of multiple comparisons [58].

3. Results

3.1. Sample

A total of $N = 119$ participants joined the study. Two participants did not complete the psychological questionnaires and were therefore excluded (IDs 2 and 76). There were four participants who indicated they felt worst in the summer, according to the respective SPAQ question, and were therefore excluded (IDs 8, 35, 36, and 94). The remaining sample included 91 women (mean age = 33.71; SD = 13.01) and 22 men (mean age = 34.33; SD = 14.03).

In the sample, 78 had a seasonality score lower than 10 (among them, 63 women) and 35 had a GSS of 10 or higher (among them, 15 women). The median seasonality score in the group with low seasonality was 4 (range 0–10) and the median in the group with high seasonality was 14 (range 11–22).

3.2. Free Recall of Emotional Pictures

There was no main effect of seasonality on the number of remembered pictures ($F(1,88.75) = 0.01$; $p = 0.933$), indicating that people with elevated seasonality remembered a comparable number of pictures as people with low seasonality. There was also no interaction between seasonality and valence of the pictures ($F(1.52, Inf) = 0.75$; $p = 0.435$). However, there was an effect for valence ($F(1.52, Inf) = 104.65$; $p < 0.001$; see Figure 1). According to Wilcoxon paired-sample tests, negative pictures were significantly better remembered than neutral pictures ($V = 2846$; $p < 0.001$), and positive pictures were significantly better remembered than negative ($V = 160$; $p < 0.001$) and neutral pictures ($V = 69$; $p < 0.001$).

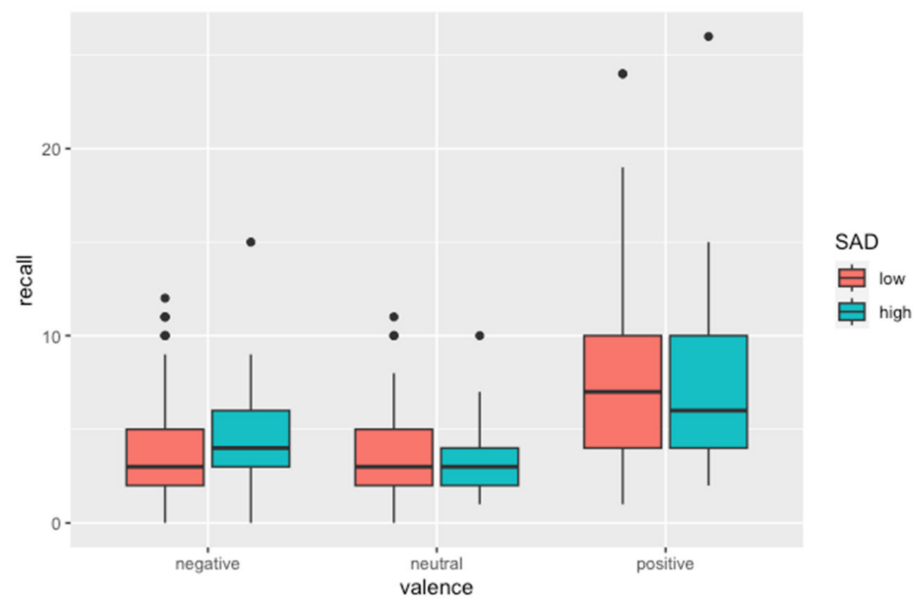


Figure 1. Boxplots of number of remembered pictures (*y*-axis) per emotional valence category (*x*-axis), grouped by seasonality group (SAD low vs. high, colors red and blue). Boxes indicate the interquartile range; the center line indicates the median. Whiskers indicate the range from the minimum (0) to the largest value that does not exceed 1.5 × the interquartile range above the upper quartile. Values outside that range are considered outliers and represented as circles.

3.3. Seasonality Effects in the EEG during Learning of Emotional Pictures

Figure 2 shows the wavelet plot of participants with low seasonality scores on electrode O1 for negative pictures, and an exemplary time–frequency intersection (10 Hz/100 ms), where the data were compared to the group with high seasonality scores.

Table 1 lists the significant results of the semi-parametric ANOVA.

Table 1. Significant results of the semi-parametric ANOVA-type statistics for the grouping factors seasonality (low vs. high), lobe (frontal, temporal, occipital), hemisphere (left, right), valence (negative, neutral, positive), frequency (alpha, gamma), and time-window (50–150 ms, 300–400 ms)¹.

	<i>F</i>	<i>df</i>	<i>p</i>
seasonality	4.44	1, 513.27	0.043
lobe	9.66	1.97, Inf	<0.001
seasonality × lobe	5.50	1.97, Inf	0.003
valence	5.02	1.93, Inf	0.011
seasonality × valence	3.31	1.923, Inf	0.037
lobe × valence	6.85	3.34, Inf	<0.001
frequency	16.88	1, Inf	<0.001
lobe × frequency	153.74	1.77, Inf	<0.001
lobe × valence × frequency	11.75	2.74, Inf	<0.001
lobe × valence × hemisphere	2.85	3.68, Inf	0.027
time-window	11.94	1, Inf	<0.001
lobe × time-window	5.51	1.36, Inf	0.011
seasonality × valence × frequency × time-window	4.35	1.95, Inf	0.018
seasonality × valence × frequency × hemisphere × time-window	3.62	1.96, Inf	0.032

¹ The table shows significant results only; the full table with all effects and interactions is provided in Table A1 of Appendix A.

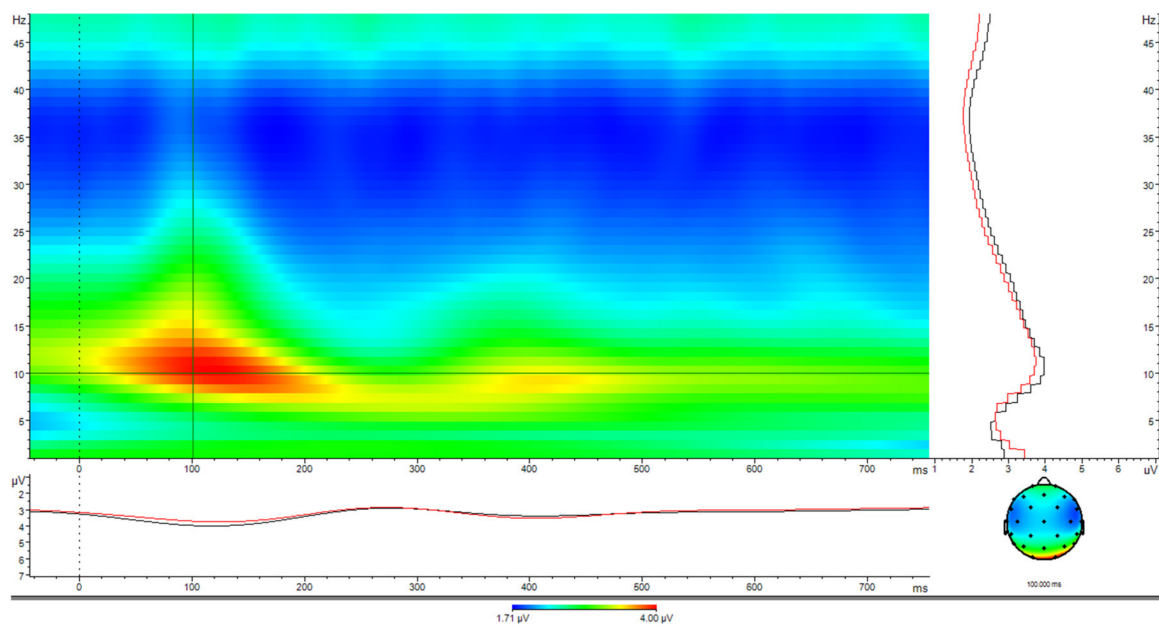


Figure 2. Wavelet plot average for participants with low seasonality scores while learning negative pictures. The top-left plot shows frequency on the y -axis (0–48 Hz from bottom to top) and time on the x -axis (40 ms before stimulus onset to 760 ms after stimulus onset). The black cross in the top-left plot represents the time–frequency intersection (10 Hz/100 ms), which is illustrated as a comparison with the group of high seasonality scores in the plots at the bottom and right side. The difference between the average of the two groups at 10 Hz is shown in the bottom-left plot with the same time-range on the x -axis but activity in μV on the x -axis (0 to 7 μV from top to bottom). The plot in the top-right panel shows activity at 100 ms over all frequencies, with the same frequency range as the top-left figure, and in μV on the x -axis (0 to 7 μV from left to right). In this figure, the black line represents the group with low seasonality scores and the red line represents the group with high seasonality scores. The topographic plot in the lower right corner shows the current density distribution at 10 Hz and 100 ms.

Following the significant results from the semi-parametric ANOVA, post hoc tests were conducted for those effects that involved the grouping factor seasonality since these were the important interactions with respect to our hypotheses. The many post hoc tests called for a correction for multiple comparisons, which we conducted by interpreting the resulting p -values at the Bonferroni–Holm corrected level of significance.

Overall, the main effect of seasonality indicated that EEG power was higher for participants with low as compared to high seasonality. This effect was particularly evident over the temporal lobe ($F(1,24) = 114.11$; $p = 0.001$).

The main effect for valence indicated that EEG power was lower for neutral pictures than for negative ($V = 2,046,729$; $p < 0.001$) and positive pictures ($V = 1,567,998$; $p < 0.001$), and higher for positive than negative pictures ($V = 1,727,382$; $p = 0.006$).

There was higher EEG power for participants with low as compared to high seasonality scores while learning negative ($F(1,24) = 49.21$; $p = 0.014$) and positive valence pictures ($F(1,24) = 68.59$; $p = 0.012$), whereas no such difference was found for neutral valence pictures. Regarding the interaction between seasonality, valence, frequency range, and time-window, there was higher power for participants with low seasonality scores as compared to high seasonality scores in the alpha range while learning positive valence pictures in the early time-window of 50–150 ms ($F(1,6) = 25.88$ $p = 0.003$) and also for negative valence pictures in the late time-window of 300–400 ms ($F(1,6) = 21.92$; $p = 0.003$). In the gamma range, all effects were significant only before but not after correction for multiple comparisons, i.e., higher power for participants with low seasonality when learning negative pictures in both time-windows (50–150 ms: $F(1,6) = 24.10$; $p = 0.009$;

300–400 ms: $F(1,6) = 16.01$; $p = 0.045$) and when learning positive pictures in the early time-window of 50–150 ms ($F(1,6) = 18.09$; $p = 0.028$).

Finally, regarding the interaction between seasonality, valence, frequency range, hemisphere, and time-window, the only significance that was statistically relevant after correction for multiple comparisons was found over the right hemisphere, where people with low seasonality scores showed higher power than people with high seasonality scores when learning negative pictures both in the alpha range in the late 300–400 ms time-window ($F(1,3) = 15.10$; $p = 0.002$) and in the gamma range in the early 50–150 ms time-window ($F(1,3) = 16.33$; $p = 0.002$). The same direction of effect was significant before, but not after correction for multiple comparisons over the right hemisphere for negative picture learning in the gamma range at 300–400 ms ($F(1,3) = 9.44$; $p = 0.027$) and for positive picture learning in the alpha range at 50–150 ms ($F(1,3) = 13.45$; $p = 0.007$). Over the left hemisphere, similar tendencies were observed for positive picture learning in the alpha range at 50–150 ms ($F(1,3) = 12.44$; $p = 0.012$) and in the gamma range in both time-windows (50–150 ms: $F(1,3) = 10.22$; $p = 0.022$; 300–400 ms: $F(1,3) = 9.45$; $p = 0.027$).

4. Discussion

The purpose of this study was to investigate a potential negative memory bias in an emotional picture learning task in summer in people who are at risk of experiencing SAD in the winter, indicated by their elevated seasonality scores. Furthermore, we aimed to examine whether brain responses to these emotional pictures were related to seasonality.

While we found no indication for a negative memory bias in summer to be associated with increased levels of seasonality, we found that brain activity during learning of emotional pictures differs between individuals with low and high scores on seasonality. Thus, even in the absence of a detectable behavioral effect, processing differences exist during remission in summer amongst individuals who are at risk of experiencing SAD in the winter.

4.1. Seasonality and Emotional Memory in the Summer

The results of our free recall experiment suggest that people with high seasonality scores did not have an emotional memory bias in summer. While we expected participants who were reporting high rates of seasonal fluctuations to recall negative items better, in contrast, participants in all groups recalled positive pictures more often than negative pictures. More generally, emotional pictures (negative and positive) were recalled more often than neutral pictures by all groups.

The most plausible explanation for this finding is that participants with seasonal symptoms of depression during winter feel good enough in summer to not demonstrate a negative emotional memory bias during this period. So far, studies reporting a negative memory bias in patients with SAD found this effect in winter [47,50,59]. This negative memory bias is well known for patients with major depression [60]. However, there are some subtle differences between the effect of depression and SAD. It was reported that patients with SAD remember more positive pictures in summer than in winter and this seasonal change distinguishes them from healthy controls [48]. The very same study found no significant difference between healthy controls and patients for the seasonal change in negative or neutral word recall performance [48]. An interventional study found that treatment of SAD improves the memory for positive contents [47]. In another experiment, patients with SAD showed impaired recognition of positive stimuli and impaired capacity to suppress responses to negative stimuli in winter, whereas healthy controls did not demonstrate such biases [59]. Our findings are in line with these prior reports. In our study, which was conducted during the remission phase in summer, the groups did not differ with respect to their responses to emotional stimuli. Thus, it is possible that people who report seasonal symptoms to occur during winter do not differ from people without such symptoms during summer with respect to emotional memory biases.

It is also possible that differences in the stimulus material explain the missing effect. Common stimuli used in emotional memory experiments include emotional faces [51,59], pictures from the International Affective Picture System [14], affective words [47], and stories [50]. We used the OASIS picture database, which is relatively new [54]. It was acknowledged by the authors of the OASIS picture database that the pictures in this database are underrepresenting the low-arousal positive and low-arousal negative segment. While we balanced the three valence groups by arousal, that is, low–middle–high arousal stimuli where proportionate in all three emotional categories, we cannot rule out that the positive images were on average more arousing and, therefore, more likely recalled.

Finally, in addition to previous reports on negativity bias in relation to seasonality [47,50,59], not all experimenters have found such an effect [61].

4.2. Seasonality, Valence, and EEG Band-Power

In contrast to behavioral results, we found significant group differences in EEG band-power responses to emotional pictures, and this difference interacted with emotional valence of the pictures. EEG band-power was highest for positive pictures, followed by negative pictures, and lowest for neutral pictures. A difference between the two groups with low and high seasonality was found only for responses to emotional pictures, i.e., those with negative and positive valence, but not for neutral pictures, indicating that there is an emotional effect when processing the pictures, which enhances the group difference.

All the significant group effects resulted in higher EEG frequency power for participants who had low scores of seasonality. This is in line with previous reports that found a general difference in brain activation between patients with SAD and healthy controls that was independent of emotional reactivity [21,51]. The localization of this effect is not as exact in the EEG as in fMRI, but we narrowed down the region of interest to lobes that were reported previously to be important for emotional processing [62]. We found that the difference between people with low and high seasonality scores was particularly strong over the temporal lobe when viewing negative or positive pictures. Our findings resemble earlier results that found differential hemisphere \times valence interactions in EEG band-power over the temporal lobe [63,64]. According to our data, the right hemisphere seems to play a more important role as it responds differentially in the two groups, especially during viewing of negative pictures. Less clear but consistent effects can be found for positive pictures, which are lateralized to the left hemisphere. This left–right differentiation for positive and negative stimuli is consistent to what was found in theta and alpha EEG band-power previously [63,64]. Furthermore, this finding supports the valence hypothesis, which assumes that the left hemisphere is dominant for positive emotions while the right hemisphere is dominant for negative emotions [65]. The finding that our results are significant in the right hemisphere, while they are significant only before but not after correcting for multiple comparisons in the left hemisphere, supports the right hemisphere model of brain asymmetry in emotional processing, which states a dominant role of the right hemisphere [65]. Therefore, our findings support the claim that the valence hypothesis and the right hemisphere model of brain asymmetry in emotional processing are not mutually exclusive [66]. The enhanced group difference over the right hemisphere for negative stimuli is also in agreement with previously reported reduced lateralization of emotional processing in people at risk for depression [11]. It should also be noted that negative stimuli seem to be generally prioritized in processing [67], which might explain the enhanced difference for negative stimuli between people with and without seasonality symptoms.

Another interesting dissociation in the alpha band is that group differences were detected in the early time-window (50–150 ms post-stimulus) for positive pictures but the later time-window (300–400 ms) for negative pictures. This effect is significant only before but not after correction for multiple comparisons in the gamma range, but with a similar pattern (early for positive pictures, both time-windows for negative pictures). Earlier timing of positive stimulus processing vs. later timing of negative stimulus processing

correlates in the alpha range was reported previously [63] and our results suggest that this timing is affected by seasonality. Gamma-band reactivity to emotional stimuli, especially of negative valence, differs between patients with depression and healthy controls [68]. A common assumption is that gamma-band involvement reflects the degree to which a stimulus is consciously processed [40]. An early process at around 150 ms post-stimulus has been suggested to mirror early attention for emotional cues [69,70], whereas processes later than 300 ms have been indicated to mirror additional emotional processing that cannot be detected when presenting neutral stimuli [71]. This late gamma component coincides with the P300 in the event-related potential and is strongly linked to the processing of unpleasant stimuli [41,44]. Since the gamma-band effects in our research did not survive the correction for multiple comparisons, they should not be overinterpreted, but could be speculatively interpreted to reflect processes of conscious experience of emotional cues to be altered in people who are at risk of experiencing seasonal symptoms.

4.3. Limitations

Since we used the seasonal pattern assessment questionnaire only to determine symptoms of seasonality, the results cannot be generalized to the situation of patients with SAD. The SPAQ is known to overestimate SAD if it is used as a screening tool [72]. Additionally, as mentioned earlier, the OASIS database is relatively new and suffers from some bias, possibly especially in the domain of positive images with respect to arousal [54]. Furthermore, the investigation was conducted in Iceland, where the summers come with almost 24 h of daylight. It is, therefore, possible that the results are not applicable to areas at less extreme latitudes. Future research should, therefore, investigate diverse samples in order to improve the generalizability of the results. Moreover, future research should investigate all-year vulnerability in people who have a clinical diagnosis of SAD.

5. Conclusions

While emotional pictures were, in general, better remembered, no negativity bias was found for free recollection in people with high vs. low seasonality scores. Specifically, the groups did not differ with respect to their recall patterns. However, regardless of this lack of behavioral differences, brain activity demonstrated an overall difference between the groups, which was enhanced in specific brain regions, time-windows, and frequency bands according to what we would expect from the literature on emotional processing. It is, therefore, possible that year-round vulnerability characterizes the brain activity of individuals who report seasonal symptoms. We suggest that these abnormalities could serve as an indicator for identifying those at risk of SAD, and thus offer an aid to plan early interventions, with the possibility that the pattern of abnormal brain activity may help to guide the design of interventional approaches. For example, we could speculate that the strong difference between the groups during processing of negative stimuli suggests that cognitive behavioral approaches that address attention bias to negative information could be beneficial in the prevention of SAD.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app13169361/s1>, Datafile.

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Data Availability Statement: The data generated for this study can be found in the Supplementary Materials.

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Abbreviations

DSM	Diagnostic and Statistical Manual for Mental Disorders
EEG	Electroencephalogram
GSS	Global Seasonality Score
ICA	Independent Component Analysis
OASIS	Open Affective Standardized Image Set
SAD	Seasonal Affective Disorder
SPAQ	Seasonal Pattern Assessment Questionnaire
S-SAD	Subsyndromal Seasonal Affective Disorder

Appendix A

Table A1. Results of the semi-parametric ANOVA-type statistics for the grouping factors seasonality (low vs. high), lobe (frontal, temporal, occipital), hemisphere (left, right), valence (negative, neutral, positive), frequency (alpha, gamma), and time-window (50–150 ms, 300–400 ms).

Seasonality	<i>F</i>	<i>df</i>	<i>p</i>
seasonality	4.442	1, 513.268	0.043
lobe	9.663	1.962, Inf	<0.001
seasonality × lobe	5.503	1.962, Inf	0.003
valence	5.015	1.934, Inf	0.011
Seasonality × valence	3.31	1.934, Inf	0.037
lobe × valence	6.849	3.346, Inf	<0.001
seasonality × lobe × valence	0.452	3.346, Inf	0.745
frequency	16.881	1, Inf	<0.001
seasonality × frequency	2.745	1, Inf	0.097
lobe × frequency	153.738	1.767, Inf	<0.001
seasonality × lobe × frequency	2.726	1.767, Inf	0.075
valence × frequency	2.163	1.963, Inf	0.106
seasonality × valence × frequency	0.692	1.963, Inf	0.508
lobe × valence × frequency	11.751	2.735, Inf	<0.001
seasonality × lobe × valence × frequency	0.587	2.735, Inf	0.612
hemisphere	0.825	1, Inf	0.362
seasonality × hemisphere	0.698	1, Inf	0.44
lobe × hemisphere	2.28	1.428, Inf	0.106
seasonality × lobe × hemisphere	0.112	1.428, Inf	0.869
valence × hemisphere	1.055	1.777, Inf	0.331
seasonality × valence × hemisphere	1.714	1.777, Inf	0.179
lobe × valence × hemisphere	2.845	3.683, Inf	0.027

Table A1. Cont.

Seasonality	F	df	p
seasonality × lobe × valence × hemisphere	1.533	3,683, Inf	0.178
frequency × hemisphere	1.099	1, Inf	0.329
seasonality × frequency × hemisphere	0.414	1, Inf	0.492
lobe × frequency × hemisphere	2.845	1,798, Inf	0.052
seasonality × lobe × frequency × hemisphere	0.298	1,798, Inf	0.742
valence × frequency × hemisphere	1.009	1,895, Inf	0.341
seasonality × valence × frequency × hemisphere	0.24	1,895, Inf	0.762
lobe × valence × frequency × hemisphere	0.392	3,744, Inf	0.796
seasonality × lobe × valence × frequency × hemisphere	0.467	3,744, Inf	0.744
time-window	11.94	1, Inf	0.001
seasonality × time-window	0.147	1, Inf	0.689
lobe × time-window	5.505	1,359, Inf	0.011
seasonality × lobe × time-window	0.206	1,359, Inf	0.779
valence × time-window	0.128	1,964, Inf	0.887
seasonality × valence × time-window	2.552	1,964, Inf	0.081
lobe × valence × time-window	1.965	2,504, Inf	0.113
seasonality × lobe × valence × time-window	0.808	2,504, Inf	0.487
frequency × time-window	1.011	1, Inf	0.32
seasonality × frequency × time-window	0.952	1, Inf	0.329
lobe × frequency × time-window	0.892	1,244, Inf	0.357
seasonality × lobe × frequency × time-window	0.261	1,244, Inf	0.697
valence × frequency × time-window	1.578	1,953, Inf	0.199
seasonality × valence × frequency × time-window	4.348	1,953, Inf	0.018
lobe × valence × frequency × time-window	2.831	2,592, Inf	0.052
seasonality × lobe × valence × frequency × time-window	1.511	2,592, Inf	0.242
hemisphere × time-window	0.786	1, Inf	0.378
seasonality × hemisphere × time-window	0.128	1, Inf	0.72
lobe × hemisphere × time-window	0.44	1,986, Inf	0.63
seasonality × lobe × hemisphere × time-window	0.021	1,986, Inf	0.98
valence × hemisphere × time-window	1.025	1,899, Inf	0.358
seasonality × valence × hemisphere × time-window	1.038	1,899, Inf	0.334
lobe × valence × hemisphere × time-window	0.32	3,425, Inf	0.85
seasonality × lobe × valence × hemisphere × time-window	0.821	3,425, Inf	0.512
frequency × hemisphere × time-window	0.001	1, Inf	0.972
seasonality × frequency × hemisphere × time-window	0	1, Inf	1
lobe × frequency × hemisphere × time-window	0.95	1,995, Inf	0.412
seasonality × lobe × frequency × hemisphere × time-window	0.18	1,995, Inf	0.828
valence × frequency × hemisphere × time-window	0.115	1,958, Inf	0.883
seasonality × valence × frequency × hemisphere × time-window	3.622	1,958, Inf	0.032
lobe × valence × frequency × hemisphere × time-window	0.087	3,649, Inf	0.99
seasonality × lobe × valence × frequency × hemisphere × time-window	0.458	3,649, Inf	0.75

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