Neurophysiological responses to pleasant emotional images: An examination of the effects of personal preference and a brief positive emotion-focused intervention

Becca Mueller

Vanderbilt University, Department of Psychology

Dr. Kujawa

March 22, 2023

Abstract

The positive valence system (PVS) is a domain associated with attention to, and engagement with, rewarding activities. Individual differences in neurological responses associated with the PVS, such as the amplitude of the late positive potential (LPP), may indicate potential risks for the development or presence of internalizing symptomology. Recent research has found that positive affect interventions can help individuals attend more to positive events; however, these interventions effects on neurological responses has yet to be studied. The present study examined differences in neural activation in relation to positive stimuli following a brief promoting positive emotions (BPPE) intervention to test its efficacy in modulating PVS functioning. EEG data was collected from a sample of 27 undergraduate students to examine associations between the LPP and categories of positively valanced emotional images, rankings of image categories by personal preferences, and intervention effects. Participants completed a battery of questionnaires, and then were randomly assigned to either the BPPE intervention or a study skills group for comparison. The BPPE group was taught to recount, savor, visualize, and plan for positive experiences while the control group learned study skills tools. EEG data was recorded while participants passively viewed positive images. Responses based on participant preferences for each category of stimuli were analyzed. We found that there was a significant difference between positively valanced images and neutral images. Significant differences were also found between participant preference rankings and neutral images, however, not in the expected direction. No significant intervention effects were found. Future studies should examine within-person effects of the intervention, as well as the efficacy of a longer positive affect intervention over multiple sessions to determine if the LPP can be modulated over time.

Introduction

Mood disorders are serious mental health conditions that have significant negative consequences for both individuals and society at large, with five out of the top 10 leading causes of disability worldwide being attributed to psychiatric disorders including depression (Patel, 2006). The rate of depression among college students is particularly alarming. A meta-analysis of 35 studies between 1995 and 2012 found that approximately 33% of college students meet the clinical criteria for depression (Sarokhani et al., 2013). Not only is this a serious issue for the individual, but depression can also pose a great burden on society. For example, depression is estimated to cause a $210.5 billion economic burden in the United States alone each year (Greenberg et al., 2015). Compounding this issue, current treatments for depression fall short of meeting clients' mental health needs. Although current depression treatments are helpful in reducing negative affect, they are largely ineffective in correcting positive emotion deficiencies, which many patients describe as their major motivation for seeking treatment (Craske et al., 2019). To combat this issue, there has been a move towards devising treatment protocols that specifically target increasing positive emotions. Research has found that targeting reward responsiveness (which is associated with positive emotionality) may be more effective than standard cognitive behavioral therapy (CBT) in both decreasing negative affect and increasing positive affect (Craske et al., 2019).

Positive Valence Systems

Positive valence systems (PVS), a domain of the National Institute of Mental Health's Research Domain Criteria (RDoC) initiative, includes both behavioral and physiological processes associated with response to potential and received rewards (Kujawa et al., 2020). This system encompasses all activity involved in anticipating, obtaining, and responding to positive stimuli, facilitating approach behaviors that motivate individuals to achieve their goals and seek out new experiences (Rackoff & Newman, 2020). Feelings of pleasure that subsequently result from activation of the PVS internally signal individuals to continue seeking out positive stimuli, and this action tendency reinforces vital advantageous behaviors necessary for growth and overall psychological well-being.

A prominent theory of positive emotions is the Broaden-and-Build model, which details how emotions such as joy, excitement, interest, and love expand the breadth of an individual's thought-action repertoire (Fredrickson, 2001). In other words, positive emotions allow for flexibility in cognition patterns that increase the array of possible responses an individual may generate in response to a situation. Over time, this process can buffer the effects of negative emotions and fuel psychological resilience by increasing the availability of cognitive resources necessary to cope with adverse events (Fredrickson, 2001).

Recent research has found that reward responsiveness, learning, and valuation are of particular importance when examining the neurological processes responsible for this phenomenon (*RdoC matrix*). When presented with the possibility for positive stimuli, dopaminergic pathways in the bilateral ventral striatum and dorsal striatum are activated in preparation for, and receipt of, reward (Kujawa et al., 2020). The magnitude of this neurophysiological response, however, varies widely between individuals due in part to individual differences in reward learning and reward valuation (Bediou et al., 2009).

Relationship Between Mood Disorders and the PVS

Internalizing symptoms are associated with both an abnormally high prevalence of negative emotions, as well as an abnormally low prevalence of positive emotions. According to the DSM-5, depression is characterized by persistent negative mood, feelings of worthlessness, thoughts of death, fatigue, difficulty concentrating, sleep disturbances, and anhedonia. To meet criteria for major depressive disorder (MDD), at least five of these symptoms must be present during a two-week period (APA, 2013). These symptoms are associated with maladaptive cognition and behavior patterns, impairing functioning of the PVS (Weinberg et al., 2016). The presence of anhedonia in particular may point to underlying abnormalities in the PVS, for anhedonia refers to the inability to experience pleasure (Gruber et al., 2010). This presents a significant problem, given that approximately 1 in 3 individuals with depression will experience clinically significant anhedonia, a symptom associated with increased likelihood for suicidality and relapse of depressive episodes (Craske et al., 2019).

In studying the impacts of internalizing disorders on the PVS, electroencephalography (EEG) has provided many insights regarding differences in neural activity to positive stimuli among individuals with and without mood disorders (Weinberg & Hajcak, 2010). EEGs record electrical activity in the brain through electrodes placed on the scalp and are interpreted in the context of event-related potentials (ERPs), which are time-locked neurological responses to specific sensory stimuli. Researchers have found that emotional images both capture attention and elicit large physiological responses, particularly as measured by the late positive potential (LPP) component which is associated with modulations of emotional intensity (Brown et al., 2012; Weinberg & Hajcak, 2010).

The LPP is a positivity in the ERP recorded as early as 200ms after stimulus onset over the occipital and parietal electrode sites (Weinberg & Hajcak, 2010). The amplitude of this positivity is increased for emotional images when compared to neutral stimuli (McLean et al., 2020). Prior research has found that pleasant images such as candy and kittens enhance LPP positivity in young children (McLean et al., 2020). Additionally, appetitive images such as romantic and erotic images have been found to enhance LPP in college students (Sandre et al., 2019). Currently, it is unclear whether there are individual differences in response to positive images based on personal preferences. However, research has found that photographs of personally relevant individuals (family and friends) may elicit more positive LPP amplitudes than more general positive images alone, for humans are more likely to attend to information that is personally relevant to the self (Viskontas et al., 2009).

Researchers have also found that people with MDD have a blunted LPP response to the presentation of positive stimuli when compared with other populations (Brown et al., 2012; Gotlib et al., 2004; Weinberg et al., 2016). This suggests that MDD impairs the effectiveness of PVS functioning not only in terms of subjective experiences of positive affect, but also in regard to neurological mechanisms (Brown et al., 2012; Kujawa et al., 2020; Pegg et al., 2021). This is believed to be due in part to increased attentional bias towards negative stimuli, and away from positive stimuli, when battling depressive symptoms (Gotlib et al., 2004). However, it should be noted that many complex, interrelated factors such as stress, maternal depression, genetics, temperament, and parenting styles are all possible contributors to this phenomenon (Kujawa et al., 2020).

Although the exact neural mechanisms underlying both the PVS and mood disorders such as depression are unknown, the relationship between them is believed to be bidirectional with changes in one component predicting subsequent changes in the other. In other words, increases in negative affect associated with mood disorders predict decreases in neural activity of the PVS, whereas high functioning in the PVS can help buffer the impact of depressive symptoms (Riskind et al., 2013). This is further supported by the fact that deficiencies in the PVS can be seen prior to the onset of psychiatric symptoms (Kujawa et al., 2020). However, it has been found that even after the completion of psychological treatments which prove successful in decreasing one's negative affectivity, deficits in the PVS remain (Chakhssi et al., 2018; Craske et al., 2019; McMakin et al., 2010; Taylor et al., 2017). As such, it is vital that further research be conducted on treatment protocols designed to promote long-term increases in positive affectivity.

Positive Affect Treatment

Although it has long been established that therapies like CBT can significantly reduce one's negative affect, these treatments do little to increase one's positive affect: the primary driving motivation cited by many individuals seeking mental health treatment (Craske et al., 2019). To fill this gap, researchers have begun studying the effects of positive affect interventions. These treatment protocols draw heavily upon findings from positive psychology research which emphasize the vital role that positive emotions play in promoting flexible cognition patterns, coping with stressful events, and fostering psychological resilience (Tugade & Fredrickson, 2006). Preliminary findings from these studies have found that positive affect treatments, or interventions designed specifically to increase positive emotions, may be more effective in treating depression than standard treatment protocols (Craske et al., 2019; Taylor et al., 2017).

Currently, interventions for depression focus solely on decreasing negative affect, like sadness and fear. However, reductions in negative affect do not necessarily result in increases of positive affect (Chakhssi et al., 2018). To combat these shortcomings, Craske and colleagues (2019) designed a positive affect treatment to test its effectiveness. Participants were taught to, 1) plan positive experiences, 2) recount these experiences, 3) identify positive aspects of situations, and 4) savor positive experiences. After 15 sessions, participants reported experiencing clinically significant increases in positive affect, in addition to significant reductions in negative affect.

Participants receiving CBT however only experienced reductions in negative affect. Similar results have been observed in other studies, each of which have found that positive affect interventions curb one's experience of negative affect in both clinical and non-clinical samples, even though it is not the primary focus of the intervention (McMakin et al., 2010; Taylor et al., 2017). Taylor et. Al (2017) also found that these effects were long-lasting, persisting for at least six months after ending treatment.

There are a few proposed explanations for these findings. Since depressed individuals not only experience reduced frequency of positive emotions, but also shorter durations of such emotions, specifically targeting processes to increase these factors simultaneously pulls attentional biases away from negative stimuli and towards positive stimuli (Thoern et al., 2016). This helps to curb maladaptive behaviors such as rumination that may result in insufficient processing of positive information (McMakin et al., 2010). Furthermore, positive affect interventions teach individuals to attribute pleasant events to personal behaviors, emphasizing the control that one has over their environment and subsequently their emotions. It expands the breadth of an individual's thought-action repertoires and serves to increase the perceived range of possible responses available, allowing for more flexible cognition patterns and increased cognitive resources (Fredrickson, 2001). Finally, savoring positive experiences reinforces behaviors that lead to increases in positive affect. Taken together, these impacts facilitate the experience of positive emotions, and in doing so, leave fewer opportunities for the intrusion of negative cognitions and subsequent experience of negative affect.

The Current Study

Adequate functioning of PVS is imperative for overall psychological well-being, particularly reducing depression risk. Preliminary findings from research into positive affect interventions provide one such method in which this can be achieved. However, investment in further research of these interventions is vital so that these treatment protocols can be standardized and implemented on a national scale, underlying mechanisms better understood, and outcomes improved. The present study seeks to fill some of these gaps in prior literature by answering the following questions: 1) How are neural responses to pleasant images (i.e., LPP) modulated by personal preferences of individuals for certain types of positive experiences, and 2) What is the effect of a brief positive-emotion focused intervention on neural responses to personally relevant pleasant images? We sought to answer these questions by administering a brief, single session version of Craske and colleges (2019) positive affect treatment as proof that PVS functioning could be modulated in-session. We expected that the LPP would track more with individual preferences of relevance than image content. We also expected that participants who received the intervention would generate a more positive LPP amplitude than those who did not receive the intervention, for the intervention seeks to increase attention to, and engagement with, positive stimuli.

Method

Participants

Participants were 27 undergraduate students at Vanderbilt University between the ages of 18 and 24 recruited through the online platform SONA. The mean age of all participants was 19.29 years (*SD* = 1.10). Of the 27 participants included, 66.7% of participants identified as female. With regard to race/ethnicity, 66.7% identified as White, 25.9% as Asian, 7.4% as Black/African American, 7.4% other race, and 3.7% Hispanic/Latinx. Demographic breakdowns by intervention group can be found in Table 1. All participants had to be fluent in English with no significant vision impairments. Eligibility based on these criteria were pre-determined through a SONA intake form. Participants were compensated for their time with class credit, receiving one SONA credit for every half-hour of participation (totaling 7 SONA credits). In addition, participants could win a variety of prizes based on their performance on a reward task. Prizes included candy, stickers, gum, scrunchies, pens, and slime. Procedures for the study were approved by the Vanderbilt University Institutional Review Board, and each participant signed an informed consent document prior to beginning the study.

Table 1.

Participant Demographics by Group

Variable	**BPPE (*n*=18)**	**Study Skills (*n*=9)**
Age	19.33 (*SD* = 1.14)	18.89 (*SD* = 0.78)
Gender (% female)	72.2%	55.6%
Race/Ethnicity (%)		
Hispanic/Latinx	5.6%	N/A
White/Caucasian	50.0%	77.8%
Black/African American	11.1%	N/A
Asian	27.8%	11.1%
Other	11.1%	11.1%

Note. One participant endorsed multiple races, and this is reflected in the overall race percentages.

Design

The experiment was mixed design, combining elements of both within and between subject designs. The independent variables were personal relevance rankings of image category and the intervention (i.e., BPPE or study skills). The dependent variable was the participant's neural response to the tasks as measured by the LPP amplitude 400-1000ms after stimulus onset at a parietal electrode site. The LPP amplitude was analyzed first across all participants on the personally relevant images (PRI) task to determine any effects of stimulus content. LPP amplitudes were then compared based on the treatment received.

Procedure and Measures

Participants scheduled a time through SONA to come into the laboratory for a 3.5-hour assessment. They began by signing an informed consent document and filling out a battery of questionnaires in REDCap. The experimenters then randomly assigned participants to either the BPPE intervention or the study skills intervention. The intervention received was determined by a random number generator. The experimenter then guided the participant through the intervention (detailed below), each of which lasted approximately 45 minutes.

Brief Promoting Positive Emotions Intervention (BPPE)

The intervention group received the BPPE training. The BPPE training/intervention consisted of six main subsections: psychoeducation, attending to positive events and gratitude, recounting and savoring positive experiences, seeking out pleasant experiences, representation and visualization of future positive events, and summary and planning. Participants were guided through these sections by a trained research assistant. A handout was provided to each participant, and they were prompted to recall and write down about recent positive experiences. The psychoeducation section sought to teach participants what emotions are and how they are experienced physiologically. Participants were asked to identify activities/events that make them happy, what cognitions accompany these events, and how these emotions feel physically. In the attending to positive events and gratitude section, participants were taught to pay attention to positive experiences and emotions in their lives. They were asked to make a list of these experiences, along with a list of things/people they are grateful for. For the recounting and savoring positive experiences section, participants were instructed to relive one of their identified positive experiences, reflecting on the experience as if they were currently experiencing it. Participants were then taught to seek out these positive experiences. Finally, the participants were taught to visualize these positive events happening in the future and create a plan to ensure they seek out positive experiences moving forward. At the conclusion of the intervention, the research assistant encouraged participants to practice these skills in their own lives moving forward.

Study Skills Training

The control group received study skills training. This training consisted of six subsections: identifying study habits, note-taking, reading, making a weekly plan, outlining campus resources, and summarizing/planning for future skill use. The experimenter began by asking participants about their current study habits, detailing what is helpful and what is unhelpful. Next, the experimenter provided the participant with information on how to best take notes to retain information presented in class. Then, the participant reflected on their reading habits and practiced reading with a purpose. The experimenter then guided the participant in making a weekly and daily plan for accomplishing their schoolwork. Participants identified what things got in the way of their learning and how to navigate these challenges. Next, the experimenter informed the participant about what campus resources are available to them (office hours, the writing study, the tutoring center, and the center for student well-being), and helped them create a plan on how to use these resources and overcome any barriers they might face in accessing them. Finally, the participant identified what skills they planed to use in the future, how they would use these skills, and described what benefits they believe these skills have in comparison to their current study habits.

EEG: PRI Task

Following the intervention, the experimenter measured the participant's head circumference to determine the correct electrode cap size. The participant was fitted with this cap, and each electrode was gelled until impedance levels were below 10 kΩ. The participants then completed a series of computerized tasks while EEG data was recorded. Each task was counterbalanced to control for fatigue effects.

Prior to the start of the PRI task, participants were asked to fill out a rank order form regarding the positive image categories. The experimenter told the participant that they were interested in what types of experiences, people, places, and things bring them personal happiness. Participants were asked to think about how much enjoyment they get from each category of positive images (i.e., sports, small animals, nature, cars, babies and children, junk food, social activities, and adventure), and to rank each category from 1 (most enjoyable for them) to 8 (least enjoyable for them) in terms of personal relevance prior to the start of the PRI task.

In the PRI task, participants passively viewed of series of 60 positive and neutral images. These images were broken down into 8 categories of positive images, and a neutral control condition. The neutral condition included images of common household objects such as cotton swabs, office supplies, socks, and a leaf. The photographs appeared in a random order, with 6 images from each category of positive stimuli and 12 images of neutral stimuli. Each image was presented for 2 seconds with a 1 second stimulus offset period. A white fixation cross was presented during the offset period. After viewing all the images once, there was a short break of approximately 1 minute before participants viewed each image a second time. The duration of the entire task lasted approximately 15 minutes. Following completion of all computerized EEG tasks, participants were debriefed on the study.

All neutral images were obtained from the International Affective Picture System (IAPS) and were selected based on having the lowest valence and arousal ratings from previous studies. Positive images were selected first from IAPS since these images have demonstrated validity in previous studies. However, there were not enough images pertaining to each category from the IAPS image set. To ensure each category had six images, additional images were pulled from Pexels and Flickr (databases of creative common images) based on their face validity with category descriptions.

EEG Processing

A 32-electrode BrainProducts actiCHamp system was used to collect EEG data. Facial electrodes were placed approximately 1cm from the outer corners of each eye, as well as 1cm above and below the right eye. An additional electrode was attached to the nape of the participant's neck for referencing HEO and VEO. EEG data were processed using BrainVision Analyzer and filtered from 0.01 to 30 Hz. Data were referenced offline to Cz. Continuous EEG data was segmented -200ms before stimulus presentation to 2500ms following stimulus presentation. Data were corrected for eye movements using Gratton’s algorithm (Gratton et al., 1983). Noisy recordings at single electrode sites were interpolated using surrounding electrodes. Semi-automatic artifact rejection was used to remove artifacts using the following criteria: maximal allowed voltage step of 50 µV/ms, maximal allowed difference of values in intervals of 175 µV (interval length: 400 ms), minimal allowed amplitude of -200 µV, maximal allowed amplitude of 200 µV, and lowest allowed activity in intervals of 0.5 µV (interval length: 100

ms). Data was also inspected visually to remove any additional artifacts. Data were further segmented by category of positive stimuli and participant's rank order preference for positive image categories, and then baseline corrected -200ms prior to stimulus presentation.

Data Analysis

Based on prior literature, we hypothesized that the LPP would differ based on image content when compared to neutral, that the LPP amplitudes would track more with individual preferences than image content alone, and that those who received the BPPE intervention would have a more positive LPP. LPP scores were extrapolated from the participants' EEG data for the PRI task 400-1000ms and 1000-2000ms after stimulus onset using a pooling of O1, Oz, and O2 electrode channels. LPP scores were then generated using the mean-amplitude method, and a residual-based difference score was calculated for responses to positive versus neutral images.

Analysis: Modulation of Neural Responses Based on Personal Preference

One repeated-measures ANOVA was conducted with the eight different categories of positive images and the neutral category. A second repeated-measures ANOVA was conducted sorting the eight categories based on the participants individual preference rankings and neutral. This was done to determine if the LPP tracked more with type of content or personal ratings. Post-hoc pairwise comparisons were also run to compare each category, as well as each ranking, with each other.

We expected to find a statistically significant effect ($p<0.05$) of type of image (positive versus neutral) on LPP amplitude, with positive images producing a larger LPP magnitude than neutral images. Furthermore, within the category of positive images, we expected that LPP magnitudes would track more with individual preference rankings rather than type of content (i.e., sports, social situations, junk food, small animals, etc.). Thus, when conducting linear regression analyses on high-low ranking splits of participants' top two and bottom two categories, we expected to find a statistically significant effect ($p<0.05$) of individual preference on LPP amplitude, with greater preference resulting in a larger LPP magnitude. This is based on prior research which indicates that the LPP is a measure of emotional modulation that directs attention towards emotional stimuli (Weinberg & Hajcak, 2010).

Analysis: BPPE Intervention Effect on Neutral Responses

Paired samples t-tests were conducted between each intervention group to compare any differences in average LPP amplitudes that could be attributed to the BPPE intervention. We expected that the BPPE group would have a significantly ($p<0.05$) more positive LPP amplitude than the study skills group. This is based on the idea that the BPPE intervention would increase participants' engagement with positive stimuli, thus generating a more positive neural response than those who did not receive the BPPE training.

Results

Sample Characteristics by Intervention Groups

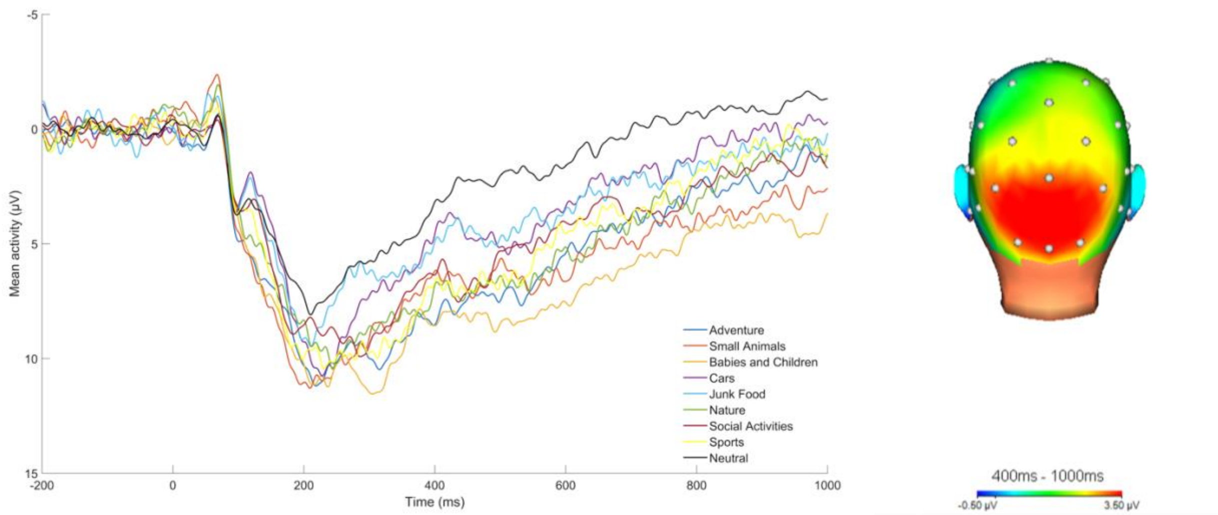
Demographic data by intervention group are presented in Table 1. The BPPE group and Study Skills intervention groups did not significantly differ on age (p=.304) or year in school (p=.415). Groups also did not significantly differ based on race (p=.470) or gender (p=.315). This indicates that the participant makeup of the two groups were comparable and could be compared for further analyses.

LPP and Image Category

First, a 2 (time window: 400-1000ms, 1000-2000ms) x 9 (category) repeated-measures ANOVA was run. The interaction between time and category was not significant ($F(8, 192) = 0.97$, $p = 0.457$, partial eta squared = 0.04), so the 400-1000ms time window was used for subsequent analyses for simplicity and in accordance with prior literature on the LPP (Weinberg & Hajcak, 2010). Grand average ERP waveforms for each picture category (e.g., adventure, small animals, babies and children, cars, junk food, nature, social activities, sports, and neutral) are presented in Figure 1 along with a scalp distribution depicting voltage differences (in mV) for positive (i.e., response to all positive categories) minus neutral images in the time-range of the LPP.

Figure 1

ERP Waveforms and Scalp Distributions for LPP for Positive Image Categories



Note. Stimulus-locked ERP waveforms (left) averaged at O1, O2, and Oz for each picture category and neutral in the time range of the LPP (400-1000ms following stimulus onset). Also shown (right) is a scalp distribution depicting voltage differences (in mV) for response to positive minus neutral images.

This was followed by a repeated measures ANOVA to examine differences between the LPP in response to each category within the 400-1000ms time window only. A significant main effect for category of image was found ($F(1,26) = 7.64$, $p<.001$, partial eta squared = 0.23). Pairwise comparisons revealed that all categories of pleasant images were significantly more positive compared to neutral (*ps*<0.034) with the partial eta squared ranging from 0.16 to 0.66. Figure 2 depicts significant pairwise comparisons between categories, and Table 2 presents the means and SDs of the LPP amplitude for each category. The LPP to babies and children was the largest, and significantly more positive than the LPP to social activities, junk food, and cars (*ps* <.001), with the partial eta squared ranging from 0.34 to 0.56. The small animals' category had the second largest LPP and was significantly more positive than the categories junk food and cars (*ps*<.001). Partial eta squared ranged from 0.34 to 0.56. The adventure category had the third largest LPP and was significantly more positive than the junk food and cars categories (*ps*<.029) with the partial eta squared ranging from 0.17 to 0.37. Finally, the LPP to nature was significantly more positive to compared to the cars category (*p*= 0.13; partial eta squared 0.22). Overall, all categories were enhanced when compared to neutral, as well as when compared to the largest and smallest categories (babies and children and cars), except for the sports category which was only significant when compared to neutral.

Figure 2

Mean LPP Amplitudes by Image Category: Significant Pairwise Comparisons

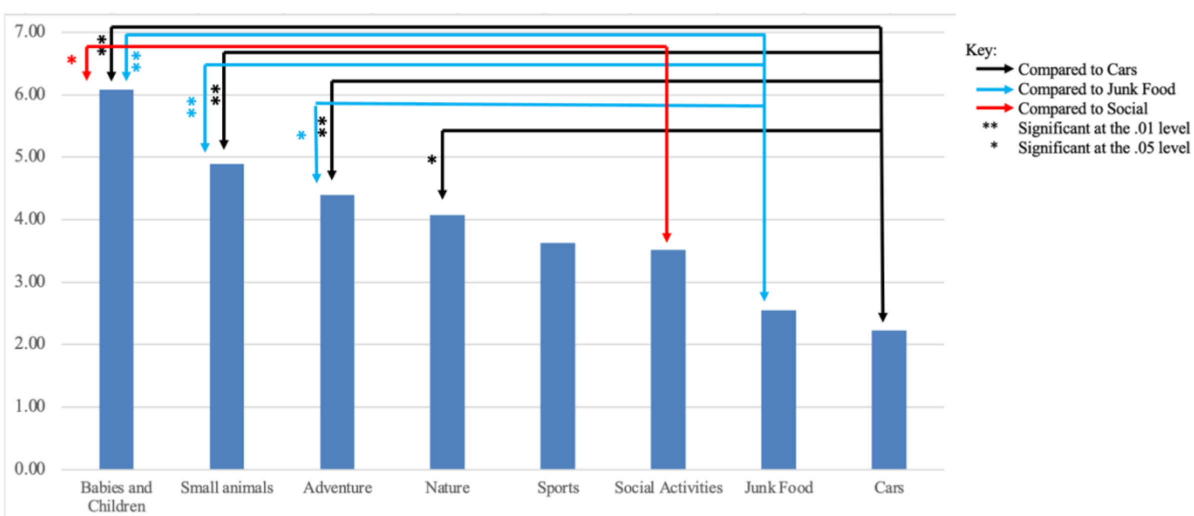


Table 2

Means and standard deviations for the LPP for each image category

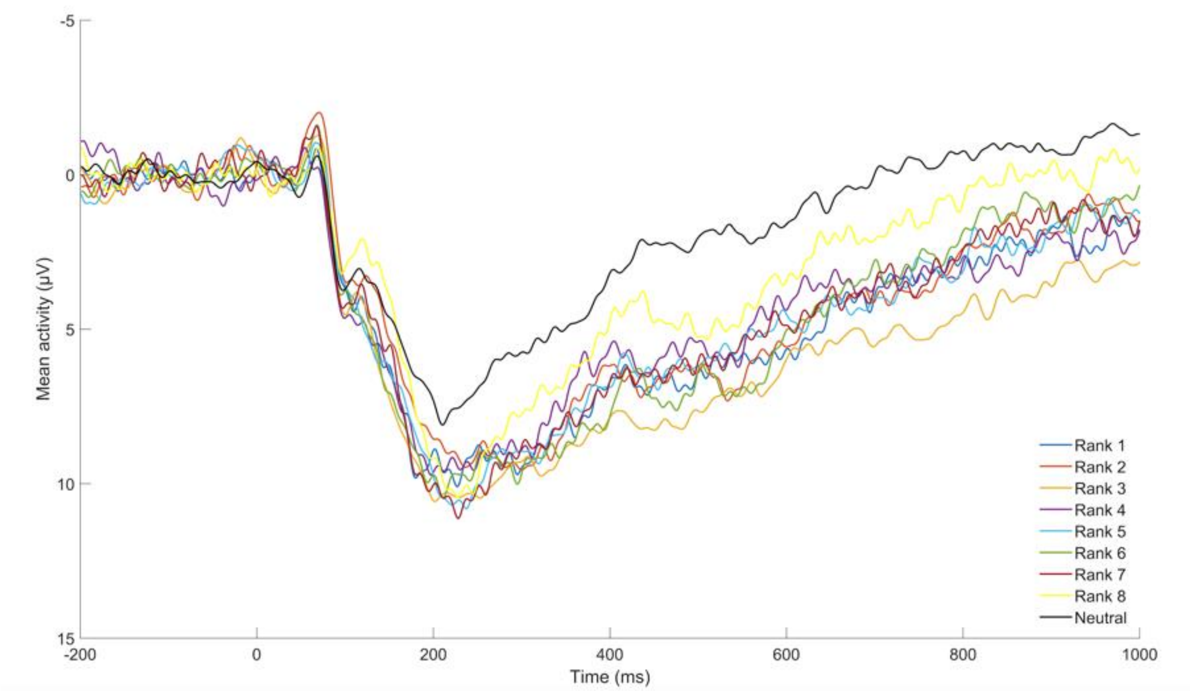
Category (400-1000ms)	*M*	*SD*
Babies and Children	6.09	5.17
Small Animals	4.89	4.19
Adventure	4.40	4.66
Nature	4.07	4.21
Sports	3.63	3.67
Social Activities	3.52	5.68
Junk Food	2.55	4.68
Cars	2.23	4.43
Neutral	0.45	4.69

LPP and Personal Rankings

A repeated measures ANOVA was run based on participants' individual preference rankings of the categories and neutral. Grand average ERP waveforms for each ranking are presented in Figure 3. There was a significant main effect found of individual preference rankings ($F(1, 24) = 6.05$, $p<.001$, partial eta squared = 0.20). In examining the pairwise comparisons, ranking 1 was expected to be more positive than ranking 2, ranking 2 to be more positive than ranking 3, and so on. Table 3 presents the relative means and SDs of the LPP amplitude for each ranking. Although all rankings were significantly more positive compared to neutral (*ps*<.029) with the partial eta squared ranging between 0.19 and 0.66, we did not find evidence of the expected pattern noted above. As expected, the LPP for Rank 8 was the smallest and significantly differed from Ranks 1-6 (*ps*<.046; partial eta squared raging from 0.18 to 0.41). However, patterns of differentiation were less clear at higher rankings. Rank 3 showed the largest LPP compared to all other rankings and was significantly more positive compared to Rank 7, in addition to Rank 8 (*ps*<.035), with partial eta squares of 0.17 and 0.34 respectively. Rank 1 on the other hand was not more positive than Rank 3, 5, and 6, but was more positive than Rank 2, 4, 7, and 8. However, there was only a *significant* positive difference between Rank 1 and Rank 8 (p<.001, partial eta squared = 0.56). Rank 2 was more positive than Rank 4, 7, and 8, but Rank 2 was only significantly more positive compared to Rank 8 (p = 0.034, partial eta squared = 0.18). All significant findings are detailed in Figure 4.

Figure 3

ERP Waveforms and Scalp Distributions for LPP for Individual Preference Rankings



Note. Stimulus-locked ERPs (left) averaged at O1, O2, and Oz for each individual preference ranking of image category and neutral in the time range of the LPP (400-1000ms following stimulus onset).

Table 3

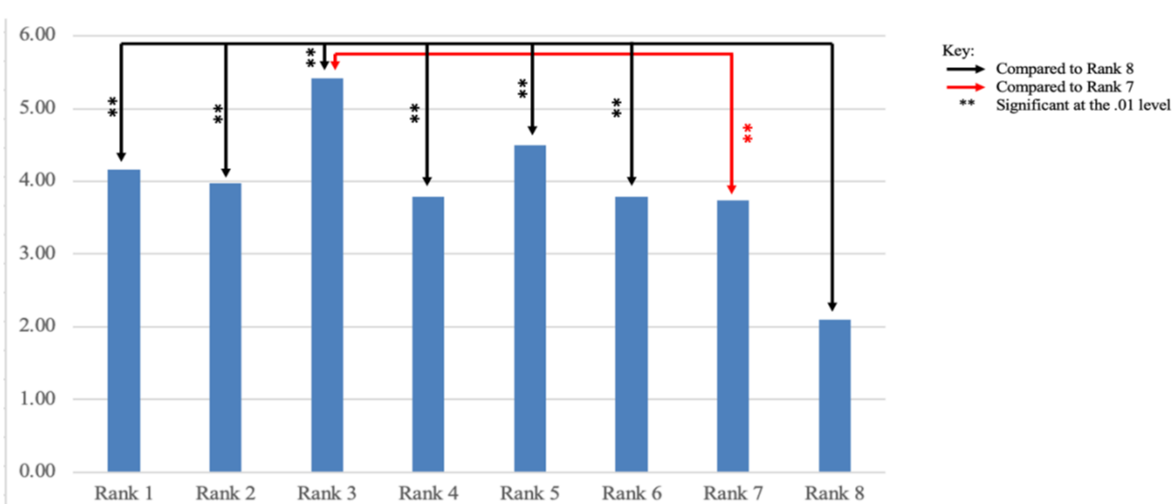
Means and standard deviations based on rankings of image categories.

Ranking (400-1000ms)	*M*	*SD*
Rank 1	4.10	4.00
Rank 2	3.63	4.83
Rank 3	4.84	4.59
Rank 4	3.58	4.49
Rank 5	4.50	4.11
Rank 6	4.14	4.45
Rank 7	3.69	4.71
Rank 8	2.15	4.42
Neutral	0.91	4.04

Note. N = 26. One less participant was included in these analyses due to missing participant rank data.

Figure 4

Mean LPP Amplitudes by Rankings: Pairwise Comparisons



Effect of Intervention Group on the LPP

A series of independent samples *t*-tests were run between intervention groups to determine if there were any differences in LPP amplitudes based on condition. LPP residual scores were used, computed by partialing out response to neutral from LPP in response to Rank 1, Rank 2, and Rank 3 preferences using linear regression and saving the unstandardized residuals. Inconsistent with hypotheses, the mean amplitude of the BPPE group was slightly less positive than that of the Study Skills group, although the difference was not significant (see Table 4).

Table 4

Results of Independent Samples t-tests Based on Condition and Ranking

Group	*N*	*M*	*SD*	*p*	*t*	*df*	*Cohen's d*
Rank 1 400-1000ms				.547	1.08	24	.45
BPPE	17	-.50	3.45				
Study Skills	9	.94	2.69				
Rank 2 400-1000ms				.775	.06	23	.23
BPPE	16	-.91	3.63				
Study Skills	9	.08	4.30				
Rank 3 400-1000ms				.470	-.87	23	-.21
BPPE	16	.65	5.87				
Study Skills	9	-.43	3.95				

Discussion

The present study examined not only the underlying mechanisms of the PVS (i.e., the LPP in relation to personally relevant images and subjective rankings), but also the effects of a single session intervention targeting deficits in this system. Results showed that all categories of positive images differed from neutral (but not equally). Rankings of image categories by personal relevance did not work out as hypothesized; however, ranking 8 was consistently less positive than rankings 1-7. Finally, the LPP did not significantly vary between treatment groups.

In alignment with the hypotheses, we found that all LPP amplitudes of positive image categories were significantly more positive when compared to the neutral images. This indicates that the images utilized were a valid measure for assessing neurophysiological responses to positive emotional images. Of note, it was found that the babies and children category produced the largest LPP response, highlighting the saliency of this image category. This is likely due to the social nature of this category (Bublatzky et al., 2014; Weinberg & Hajack, 2010). On the other hand, the categories junk food and cars had the lowest LPPs when compared to neutral. This is presumably because these categories may not have been as salient compared to the other categories. However, more work is needed to determine why these distinctions exist, for they are not based on subjective preferences as indicated by the results of the ranking findings.

Contrary to the hypotheses however, we did not find that individual preferences for the different image categories modulated the LPP amplitude. The order in which participants ranked the categories did not produce any notable pattern in terms of the positivity of the LPP response, except for participants' last ranking (Rank 8). Rank 8 was significantly less positive than rankings 1-7. This finding may be due to differing interpretations by participants on what "enjoyable" means; thus, creating random variation in terms of how each participant ranked the categories. On the other hand, this could also suggest that the LPP may only be modulated by image content and not personal liking/relevance. Rankings are a subjective rating, and neural signals may be a more objective measure of salient stimuli. However, no prior research has been conducted on this topic, and as such, more evidence is needed to shed light on these findings.

Additionally, we did not find that the BPPE intervention had any significant effects on the LPP when sorted by participant preferences. This finding was contrary to the original hypotheses. Prior research on positive affect interventions has shown that these interventions improve participant's subjective feelings of happiness and well-being, while simultaneously decreasing symptoms of depression and anxiety (McMakin et al., 2010; Taylor et al., 2017). These effects have been seen both within sessions and at follow-up appointments. Furthermore, prior research has also found that individuals with depression have blunted LPP amplitudes (Brown et al., 2012; Gotlib et al., 2004; Weinberg et al., 2016). Thus, we expected an upregulation of the LPP in response to participants' subjective increases in positive affect following the BPPE intervention. These present findings may be due to a few factors. First, the sample size was relatively small ($N= 27$). Thus, if the intervention only had minor effects, these effects may not have been captured at the level of significance. Furthermore, the participant sizes of the BPPE group and the Study Skills group were uneven after data cleaning (Ns=18 and 9 respectively). This skewness between groups may also have made it difficult to capture any effects. Moreover, by having research assistants implement the intervention, it is possible that the intervention was not provided in a consistent and effective manner, which may have further skewed the results. Finally, it may be possible that a longer and more consistent intervention is needed to change neurophysiological responses (i.e., the LPP). Effects may not be immediately present at post-treatment, and it may take a follow-up period to see any impacts.

There are other limitations of the study that are important to note. The present BPPE intervention was only a single 45-minute session. A longer intervention over the course of multiple sessions might be necessary to note any significant changes. Furthermore, the LPP was only measured once to reduce burden on participants, after the intervention. Having a baseline measured prior to the intervention would be helpful to determine if there are within-person changes in the LPP. As such, future research should investigate the impacts of a longer intervention, ideally with baseline LPP measurements and a larger sample size, to determine if the intervention has any significant impacts on neurophysiological responses. Moreover, we were unable to study the impact of depression symptomatology on the LPP in the current study as only three of the 27 participants met the criteria for clinical cutoffs in the current sample. Future research should study the impact of depression symptomatology has on the LPP in relation to positive affect interventions to see if there are any moderating effects.

The current study has potential theoretical implications regarding the PVS and the importance of the LPP in terms of its association with emotional regulation and its validity as a measure to assess internalizing symptomatology. Results of this study highlight the methodological utility of using positive emotional images to elicit LPP responses. Based on the results of this study, these images can be of a wide range of stimuli; however, to elicit higher LPP amplitudes categories such as babies and children are most effective. Furthermore, it also supports prior literature indicating that the LPP is a measure of sustained emotional attention (Brown et al., 2012, Bublatzky et al., 2014). Given the limitations present in the study, future research should focus on obtaining a larger sample size, examining within-person effects, and analyzing the relationship between internalizing symptomology and intervention effects on the LPP.

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