EMOTION-MODULATED ELECTROPHYSIOLOGICAL REACTIVITY: A COMPARISON OF STATIC SCENE AND DYNAMIC VIDEO STIMULI

by

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(Under the Direction of Dean Sabatinelli)

ABSTRACT

Dynamic and static stimuli could offer unique insights into emotional processing in the brain. This study examines neural responses to emotional stimuli presented as still images compared to videos using EEG methods. By employing steady-state visually evoked potentials (ssVEPs), late positive potential (LPP), and early posterior negativity (EPN) techniques, we hypothesize distinct brain reactions to emotional and neutral stimuli across the two modalities. Arousal and valence ratings from participants demonstrate significant variations across emotional categories. Results indicate that both emotional videos and pictures modulate physiological responses. Correlations of individual scenes and participants found significant relationships across physiological measures. Comparing LPP and ssVEP responses suggest that the two responses measure similar cognitive processes.

INDEX WORDS: electrophysiological reactivity, emotional stimuli, emotion processing, steady-state visually evoked potential, late positive potential, early posterior negativity, cognitive processing

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INTRODUCTION

Overview

The study of emotion is a complex and multifaceted field that presents a significant challenge due to the absence of clear consensus on its definition (Frijda & Scherer, 2009). This lack of consensus could be due to the intricate nature of emotions, their subjective experience, and the diverse range of scholarly disciplines that examines them (Lang, 2010). Despite the inherent difficulty with defining emotions, scientists have made attempts to study and measure them through observable and measurable responses. Specifically, the data of emotion can be captured and examined using three primary modalities: the language of emotion (expressive and evaluative), reflexive physiological changes (somatic and automatic), and observable behavior (approach, avoidance, freezing, performance deficits/enhancements; Lang, 1988). While language is exclusive to humans, many other mammals exhibit similar behavioral and physiological responses in situations involving emotion (e.g., pain threat or reward; Frijda, 2007). This overlap between humans and other mammals has led to the idea that emotions are rooted in primal behavior and have been retained because they promoted survival (Lang, 2010). Fear, for example, can be seen as a disposition to flee, accompanied by physiological reactions. The brain circuits underlying such physiological reactions are believed to be located primarily deep within the cortex and subcortex. These circuits are considered motivational and play a role in directing and energizing behavior to achieve survival goals.

The results of factor analyses have led to the proposal of two main motivational systems: hedonic valence (positive/pleasant/appetitive vs. negative/aversive/defensive) and arousal (intensity of activation). The aversive system is associated with negative affect, while the appetitive system is associated with positive affect (Bradley & Lang, 1994; Russell & Feldman Barrett, 1999). These motivational systems have been further explored in a mammalian brain model, which has guided investigations into the human brain (Lang, 2010). However, to investigate emotional reactions in the human brain itself, empirical paradigms must be developed that can reliably elicit emotion and engage these motivational systems.

Research on Eliciting Emotion in the Laboratory

An essential part of creating successful paradigms is employing stimuli that reliably elicit emotional responses. In the past, mental imagery (Lang, 1979), music (Sutherland et al., 1982), and odors (Kadohisa, 2013) have been empirically used to consistently evoke emotional responses. Other techniques, such as creating a social environment through which to elicit the target response (Bushman & Baumeister, 1998) or asking participants to recall emotionally charged memories (Prkachin et al., 1999), have also been employed.

Emotion Elicitation via Still Images

Despite the occurrences of other approaches, the most widely used method for evoking emotional responses remains the use of still images (Bradley et al., 2001; Codispoti et al., 2006; Junghöfer et al., 2001; Keil et al., 2013; Schupp, Cuthbert et al., 2004). The practicality of using still images, exemplified by their ability to be manipulated in terms of size, color, resolution, hue, saturation, contrast, brightness, orientation, and sharpness, contributes to their widespread adoption in laboratory research settings (Kim et al., 2018). Additionally, paradigms that use still pictures have the advantage of using previously validated picture sets.

The International Affective Picture System (IAPS)

Earlier studies employed picture sets to elicit specific emotional responses, such as fear or threatening reactions (Öhman, 1986), or to present targeted facial expressions to gauge emotional states (e.g., surprise and disgust; Ekman & Friesen, 1977). Subsequently, a standardized alternative, known as the International Affective Picture System (IAPS; Lang et al., 1997a), was developed that now encompasses a collection of approximately 1,100 images. These images have been sorted into the categories of *pleasant*, *neutral*, and *unpleasant* with the Self-Assessment Manikin (SAM) tool (Bradley & Lang, 1994). Instead of focusing on evoking a specific emotional response, this standardized set comprises a broad spectrum of content themes, including but not limited to snakes, babies, and landscapes, that are designed to induce varying levels of arousal and emotional valence. This strategic categorization results in an affective landscape where, for example, an erotic image, which elicits high arousal and high valence (pleasantness), may be contrasted sharply with a graphic depiction of mutilation that invokes high arousal but low valence (unpleasantness). Extensive research has been conducted on these images, which are typically displayed for durations ranging from 25 ms (Codispoti et al., 2009) to 6 s (Codispoti et al., 2012). These images have been effectively used to stimulate both cognitive (Murphy & Isaacowitz, 2008; Padulo et al., 2020; Talmi et al., 2008) and physiological (Codispoti et al., 2012; Keil et al., 2008; Miskovic et al., 2015; Schupp et al., 2007) responses in past studies, marking their significant contribution in this area of research.

Emotion Elicitation via Video Images

While still images have been extensively used to elicit emotional responses in a research setting, studies have also examined the emotional effects of video clips (Carvalho et al., 2012; Gabert-Quillen et al., 2015; Gross & Levenson, 1995; Hewig et al., 2005; Samson et al., 2016).

Video clips, much like their still counterparts, have been analyzed through the dual lens of dimensional (Aguado et al., 2018; Goldberg, 2014) and categorical (Karama et al., 2011; Kreibig et al., 2007) emotional perspectives in affective research. These clips, rich with dynamic stimuli, have demonstrated the ability to spark cognitive (Goldin et al., 2005; Uhrig et al., 2016) and physiological responses (Christie & Friedman, 2004; Gomez et al., 2005; Hu et al., 2017). In the pursuit of emotional reactions for laboratory research, there appears to be a reliance on professionally crafted materials (Detenber & Reeves, 1996; Schaefer et al., 2010), such as studio film clips, advertisements, and music videos (Koelstra et al., 2012). This preference has left the domain of naturalistic or amateur-shot videos relatively unexplored. However, a theoretical concern could be raised regarding the potential impact of the polished nature of professional footage on emotional responses. Although empirical studies directly addressing this concern are currently lacking, the presence of elements that deviate from naturalistic or amateur-shot videos may introduce confounds that could influence the interpretation of emotional reactions.

Limitations of Past Emotional Video Datasets

Along the same lines as the IAPS, there have been attempts to create empirical, standardized emotional video databases to be used by future researchers (Carvalho et al., 2012; Cowen & Keltner, 2017; Detenber & Reeves, 1996; Douglas-Cowie et al., 2011; Gilman et al., 2017; Gross & Levenson, 1995; Hewig et al., 2005; Koelstra et al., 2012; Liu et al., 2018; Philippot, 1993; Rottenberg et al., 2007; Samson et al., 2016; Schaefer et al., 2010; Soleymani et al., 2012; Zupan & Babbage, 2017). Some of these video databases, however, have limitations that might make them unsuitable for measuring physiological responses.

Apart from three databases (Carvalho et al., 2012; Detenber & Reeves, 1996; Koelstra et al., 2012), all those cited above include video clips of varying lengths. Using stimuli of varying lengths could confound emotional content with duration, thereby making conclusions about emotional effects impractical. This is especially true for sets that include longer videos ranging between 1–15 min (Carvalho et al., 2012; Detenber & Reeves, 1996; Hewig et al., 2005; Koelstra et al., 2012; Liu et al., 2018; Schaefer et al., 2010; Soleymani et al., 2012; Zupan & Babbage, 2017), as longer videos could result in participants habituating to the stimuli or experiencing multiple, distinct emotional reactions (Samson et al., 2016).

Another issue is that many of these databases include clips that either have no sound (Carvalho et al., 2012; Cowen et al., 2017; Gilman et al., 2017; Philippot, 1993; Samson et al., 2016) or have additional narration or music layered over the natural dialogue and sounds (Detenber & Reeves, 1996; Douglas-Cowie et al., 2011; Gross & Levenson, 1995; Hewig et al., 2005; Koelstra et al., 2012; Liu et al., 2018; Rottenberg et al., 2007; Schaefer et al., 2010; Soleymani et al., 2012; Zupan & Babbage, 2017). Emotional responses can be significantly influenced by the congruence between auditory and visual stimuli in video clips. Misalignment between the overlaid narration or music and the visual content may unsettle the natural audiovisual perception processes. For example, incongruity could arise from an action-packed scene accompanied by a calming soundtrack, or when the facial expressions onscreen are out of sync with the mood of the accompanying musical composition. Such discordance can lead to diminished emotional responses, evidenced in both physiological (Baumgartner, Esslen et al., 2006; Baumgartner, Lutz et al., 2006; Jeong et al., 2011) and self-report responses (Vines et al., 2011). The inherent complexity of accurately balancing audiovisual elements underscores the need for meticulous design in stimulus creation to avoid any potential sensory discordance (see Schreuder et al., 2016, for a comprehensive discussion).

The nature of professional-grade films, characterized by rapid cuts of camera angles and professional actors, can also introduce elements that can potentially diminish the ecological validity of emotional video datasets. The precision of postproduction effects, such as lighting and sharpness, while aesthetically appealing, may inadvertently disrupt viewers' authentic emotional experiences, which are foundational to embodied cognition. This concept suggests that our cognitive processes are intertwined with our bodily experiences and environment (Hardy 2021; Wilson, 2002). A divergence from genuine emotional triggers in professional films might lead to shallower emotional engagement and subsequently a diminished physiological response (Davis et al., 2010; Wells and Petty, 1980; Domasio, 1994). Moreover, the very mode of video delivery, especially the degree of 'professionalism', can influence narrative transportation. This immersive phenomenon allows viewers to lose themselves in a story, feeling events as real (Green & Brock, 2002). Professional actors, while skilled, might unintentionally obstruct this transportation if perceived as inauthentic or less genuine (Slater and Rouner, 2002; Gordon et al., 2017). Furthermore, the polished nature of professional videos might undermine the viewer's sense of 'presence', a sensation of genuinely being within a narrative environment (Biocca, 1997). Spatial presence, building upon this concept, encapsulates the sensation that viewers experience, giving them a sense of immersion and interaction with media platforms such as print (Green & Brock, 2000), television (Kim et al., 2017), video games (Lee, 2004), and virtual environments (Ahn et al., 2016). This feeling mirrors the engagement one would have within the tangible confines of the real world (Biocca, 1997; Slater and Wilbur, 1997). Professional videos, by curating every detail, might reduce the raw emotional cues necessary for spatial presence, resulting in less immersion and thereby a reduced emotional impact.

Considering all this, while the systematic evaluation of professional films' impact on these cognitive phenomena is yet to be done, insights from research comparing emotional responses between computer-generated and real-life stimuli are enlightening. Some studies have noted variations in color (Simmons, 2006; Valdez & Mehrabian, 1994) and angular sharpness (Halper et al., 2003; Monö, 1997) that can modulate emotional responses. Likewise, videos with live-action individuals might lead to more significant occipital cortex activation than computer-animated videos (Mar et al., 2007). It suggests that the very precision of professional videos could paradoxically diminish their efficacy for capturing true emotional responses in research contexts.

Past Research Comparing Still Images and Videos in Emotion Elicitation

Videos and still images are commonly used to trigger emotional responses, and there have been efforts to standardize these stimuli. However, few studies have compared the effectiveness of these two methods in eliciting emotions in both self-report and physiological contexts. A literature search found only five studies (Boğa et al., 2022; Lench et al., 2011; Novak & Solcova, 2017; Siedlecka & Denson, 2019; Uhrig et al., 2016) comparing emotional reactivity between still pictures and videos. Three publications (Boğa et al., 2022; Lench et al., 2011; Siedlecka & Denson, 2019) were review papers investigating different methods of eliciting emotions along discrete emotional dimensions. One review (Lench et al., 2011) indicated that still pictures, in general, were more effective in eliciting target emotions, while another (Boğa et al., 2022) suggested that videos were more effective. In contrast, the review by Siedlecka and Denson (2019) reported equal effectiveness for still pictures and videos in eliciting emotions, with the exception of sadness, for which films were deemed superior.

Only two studies directly compared both modalities, and their findings were also mixed. Uhrig et al. (2016) indicated that emotional still pictures evoked stronger subjective responses than did neutral still pictures but found less evidence for the superiority of emotional videos over neutral videos. In contrast to these findings, Novak and Solcova (2017) found that emotional films exerted a greater impact on subjective and physiological responses than did neutral stimuli. However, they found less pronounced differences in responses to emotional and neutral still images (Novak & Solcova, 2017). One notable limitation in the past literature comparing still images and videos is that existing studies have employed only self-report and peripheral psychophysiological measures (e.g., skin conductance, heart rate, facial electromyography [EMG]). Such approaches leave a gap in the literature regarding the comparison of these modalities using central psychophysiological measures such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG).

Neuroimaging Studies of the Emotional Effects of Videos and Still Images

While numerous studies have explored the emotional impact of videos and still pictures individually through various neuroimaging techniques, there is a notable gap in the literature concerning within-subject comparisons of these modalities utilizing neuroimaging measures. Specifically, no studies have directly compared the emotional responses elicited by videos and still pictures within the same subjects using fMRI or EEG recordings. Despite this absence, there does exist a substantial body of research dedicated to understanding the emotional impact of videos and still pictures independently. These investigations employing fMRI and EEG methodologies have yielded valuable insights into the neural correlates of emotional processing and the potential emotional impacts of videos and still images. The aim of the following review is to synthesize and present the collective insights gained from neuroimaging studies conducted on videos and still images to shed light on their contributions to our understanding of emotional processing. First, a summary of relevant EEG studies and their findings is presented, followed by a discussion of fMRI approaches and the relevant findings.

Electroencephalography (EEG) Studies

Electroencephalography (EEG) captures electrical brain activity through electrodes positioned on the scalp. This method predominantly detects signals from pyramidal neurons found in the cortical layers (Elston, 2003). Their unique orientation, parallel to each other, combined with the extended reach of their apical dendrites, generates a pronounced dipole during synaptic transmission-induced action potentials (Klein, 2006). When numerous neurons synchronize their action potentials, a current is produced, traveling through various brain layers to the scalp (Nunez, 1981). This current, represented by weak brain waves, is then amplified, and recorded by the attached electrodes. This technique is used for a variety of clinical and empirical applications. One popular empirical application is gauging emotional responses, as it can measure and record activity occurring in a matter of milliseconds (Perrachione & Perrachione, 2008) and is much less expensive than other types of neuroimaging (e.g., fMRI or magnetoencephalography). Emotional reactions to stimuli using EEG have been extensively studied. Two popular methods are the analysis of event-related potentials (ERPs) and steady-state visually evoked potentials (ssVEPs), both of which will be used in this dissertation research. It should be noted that researchers using such techniques have generally employed brain-wave oscillations ("waves" or "bands") as dependent variables to reflect differential behavioral processes depending on their location. For example, it is thought that alpha waves over the occipital region indicate states of relaxation, while theta waves over the temporal region relate to memory performance (see Bazanova & Vernon, 2014, and Klimesch, 1999, for full reviews).

The following subsections will, first, provide an overview and definition of important terms in EEG analysis, followed by a discussion of the relevant findings from studies using these approaches.

Overview of ERP Methodology

Most past research has used ERP methodology to gauge emotional reactions to emotional stimuli. For example, two of the more popular emotional ERPs, organized temporally, are the early posterior negativity (EPN) and the late positive potential (LPP), both of which have been shown to exist within audio and visual processing. It is thought that modulation of both the EPN and the LPP are representative of the arousal dimension in the biphasic emotional model, meaning that if an emotional stimulus has a greater ERP than a neutral stimulus, this difference indicates that the emotional stimulus is more arousing than the neutral stimulus.

The analysis of ERPs involves presenting a participant with a stimulus multiple times, isolating the potentials within a prescribed time window, noting the direction of the response, and taking the average of magnitudes in the responses of interest. Some researchers have referred to the temporal component of an ERP as “1,” “2,” or “3,” which indicate, respectively, the first, second, or third deflection in response to a stimulus, not specifically the time window in which it occurred. For example, the average magnitude (microvolts; μV) of a peak within a certain time window (100 ms using a P100 analysis) can be compared under different conditions (Srinivasan, 2007). Therefore, “P100” (or P1) denotes that the researchers examined the average magnitude of μV in a positive direction at approximately 100 ms (or the first deflection) after stimulus onset and compared the averages across different experimental conditions (see Luck, 2014, for a full review of ERP). The process of averaging is necessary to help reduce data noise by diminishing the effect of extraneous factors of activity unrelated to the outcome of interest (Farkas et al., 2019). However, the standard for taking the average of peak magnitudes over multiple trials presents a limit to experimental design. Accordingly, researchers must avoid overgeneralizing the meaning of ERP components. The subtle differences observed across the scalp and across time do not indicate wholly distinct processes. For example, although the P300 and the late positive potential (LPP, ~400–900ms; Schupp et al., 2007) take place, as their names suggest, at different timepoints, both reflect similar cognitive processes.

Past ERP research

Late Positive Potential (LPP)

The LPP provides an observable measure of emotional processing occurring in the brain (Hajcak et al., 2012). It was initially discovered when researchers observed that emotional effects extended beyond the P300 latency time (Lang et al., 1997b; Palomba et al., 1997). Studies using fMRI have suggested that the LPP may originate from extrastriate cortical areas, as well as limbic structures like the amygdala and orbital frontal cortex (Sabatinelli et al., 2007, 2013).

Limited research has been conducted on the auditory LPP, with only two studies having examined recorded electrophysiological responses to auditory stimuli (Brattico et al., 2010; Vormbrock et al., 2023). These two studies found that emotional sounds (e.g., music and nature) elicited an arousal effect similar to that typically found in the visual LPP literature. Notably, the timing of the auditory LPP effect reported by Brattico et al. (2010) was slightly later than the typical range, occurring between 1000–1800 ms, but falling within the possible timeframe (see Pastor et al., 2008).

In the visual domain, the LPP has been seen as a positive deflection over midline parietal electrodes, emerging approximately 400 ms after scene onset and persisting as long as 1000 ms (Cuthbert et al., 2000; Schupp et al., 2007). The LPP aligns well with the biphasic model of emotion and has been extensively investigated using visual scene presentation paradigms (Bradley, 2009; Bradley et al., 2007; Russell, 2003). Typically, participants in such studies are presented with grayscale photos from the IAPS with standardized valence and arousal dimensions, ranging from brief exposures of 25 ms to longer durations of up to 6 s (Codispoti et al., 2009, 2012). While self-reported arousal ratings have been shown to correlate strongly to LPP modulation, specific content, such as erotica and mutilation scenes, has been documented as eliciting greater LPP amplitudes than expected based on arousal ratings alone (Weinberg & Hajcak, 2010). Such findings imply that scenes depicting evolutionarily significant content may exert a pronounced impact on the LPP, even if participants report similar levels of arousal to other stimuli. Furthermore, the LPP has also shown resilience against habituation to scene repetition, scene complexity, and color, making it one of the most widely used ERPs for examining emotional processing (Bradley, 2009; Codispoti et al., 2006, 2007, 2012; Miskovic et al., 2015).

Early Posterior Negativity (EPN)

The EPN is thought to represent an early stage of heightened perceptual processing associated with increased emotional arousal (Junghöfer et al., 2006; Schönwald & Müller, 2014; Schupp et al., 2006). The visual EPN is characterized by a relative negative shift recorded over lateral occipital sensors approximately 150 to 300 ms after the onset of a scene (Junghöfer et al., 2001; Schupp, Cuthbert et al., 2004). The auditory EPN has been reported to occur within the same time window but has been shown to exist more in the parietal areas of the scalp (Jaspers-Fayer et al., 2012; Mittermeier et al., 2011).

Previous studies have demonstrated that the EPN can be modulated by various emotional stimuli, including scenes (Junghöfer et al., 2001), faces (Schupp, Öhman et al., 2004), written words (Kissler et al., 2007) and sounds (Jaspers-Fayer et al., 2012; Mittermeier et al., 2011). Most research on EPN modulation has examined specific stimuli content, with a particular focus on the influence of valence and arousal of presented stimuli. Existing studies have generally focused on visual EPN, although a literature search revealed two studies reporting emotional effects on the EPN in association with auditory stimuli (Jaspers-Fayer et al., 2012; Mittermeier et al., 2011). The relevant findings of these studies are presented in the following subsections.

Mittermeier et al. (2011) and Jaspers-Fayer et al. (2012) both examined differences in EPN for emotional words and syllables and for neutral controls at various tonal frequencies. Both studies found that the auditory EPN reflected increased negativity for emotional stimuli compared to neutral stimuli, which could indicate a heightened neural response to emotionally arousing auditory content (Jaspers-Fayer et al., 2012; Mittermeier et al., 2011). However, there was a temporal discrepancy between the two studies, with one finding a distinctive peak at 170 ms (Mittermeier et al., 2011) and the other locating this peak between 252–392 ms (Jaspers-Fayer et al., 2012). Additionally, it is noteworthy that both studies employed PZ sensors to examine the auditory EPN, which has typically been associated with more parietal brain regions compared to the traditional visual EPN. This observation suggests the involvement of distinct neural structures in the processing of visual and auditory emotional stimuli. The discrepancy in the temporal dynamics of the EPN between the two studies further underscores the complexity of the EPN response and highlights the need for a comprehensive understanding of its underlying mechanisms.

Research on the visual EPN has yielded abundant findings. Junghöfer et al. (2001) demonstrated its resilience to grayscale versus color picture presentation. Bradley et al. (2007) revealed a stronger EPN modulation by simple figure-ground scenes than by complex scenes, regardless of emotional self-reports. These findings suggest that picture complexity may partially influence the EPN, emphasizing the significance of balancing stimulus complexity for laboratory research through approaches such as adjusting JPEG file size (Donderi, 2006).

In addition, some studies have reported a bias in the visual EPN modulation for pleasant scenes rather than aversive scenes (De Cesarei & Codispoti, 2006; Flaisch et al., 2008; Frank & Sabatinelli, 2019; Schupp, Cuthbert et al., 2004; Weinberg & Hajcak, 2010), whereas other studies have not found such a bias (Sabatinelli et al., 2013). Inconsistent findings may be partly attributed to differences in experimental design, particularly in controlling for arousal ratings between categories. A study by Frank and Sabatinelli (2019) investigated the pleasantness bias of the EPN using complementary fMRI measures and found that erotic scenes and joyful scenes elicited greater EPN modulation than aversive mutilation scenes, suggesting a potential pleasure bias in EPN responses. Notably, fMRI measurements revealed similar modulation patterns in the lateral occipital cortex, supporting its contribution to EPN responses (see Schupp et al., 2006, 2007). In contrast to Frank and Sabatinelli (2019)'s findings, Farkas et al. (2019) demonstrated that (a) erotica elicited larger EPN amplitudes than equivalently arousing victory scenes and (b) EPN modulation was stronger for nonerotic nude scenes than for erotic scenes. These findings suggest that the EPN could be modulated by both the emotional intensity of the scenes and the presence of unclothed body parts (Farkas et al., 2019).

Steady-State Visual Evoked Potential (ssVEP)

The ssVEP is a measurement of neuronal activity in a “steady-state” response to rapid visual stimuli (Regan, 1989; Spekreijse et al., 1985) that takes an oscillatory waveform (Wang et al., 2007; Wieser et al., 2016). Compared to traditional ERP measurement, ssVEPs allow for better localization of neuronal generator origin and the evaluation of neural activation amplitude on a trial-by-trial basis (Wang et al., 2007; Wieser et al., 2016). The extended visual cortex, including the primary visual cortex (V1), extrastriate cortex, and higher-order cortices such as the midtemporal regions and intraparietal sulcus (IPS), has been suggested as the neuronal source of the ssVEP signal (Di Russo et al., 2007; Müller et al., 1997; Pastor et al., 2008).

Compared to traditional ERP components, ssVEPs exhibit excellent signal-to-noise ratio characteristics (Srinivasan et al., 2006). They provide unique insights into the neurophysiological aspects of emotion processing and attention, as ssVEPs have been shown to be sensitive not only to sensory responses but also to affective and attentional features of experimental tasks (Keil et al., 2003, 2008, 2009, 2012; Moratti & Keil, 2009; M. M. Müller et al., 2003). For example, studies presenting participants with emotional visual stimuli have observed decreased ssVEP amplitudes for emotional scenes relative to neutral scenes (Bradley et al., 2012; Keil et al., 2003, 2008, 2009). Conversely, a modified paradigm involving the superimposition of a flickering stimulus (e.g., a border or dots) on static emotional or neutral images revealed a decreased ssVEP amplitude in response to emotional scenes compared to neutral scenes (Kemp et al., 2002, 2004). This reverse response has been interpreted as attentional interference (Keil et al., 2005), with heightened attention drawn to the scene and away from the overlaid flickering stimulus. In line with these findings, a recent study by Sabatinelli et al. (2023) observed an attentional interference effect in the use of emotional videos such that these videos elicited lower ssVEP responses than neutral videos, thereby indicating a distinct neural response.

The analysis of ssVEPs overcomes the limitations of multiple-trial ERP analysis by enabling the examination of data over single trials, thereby providing valuable insights for different experimental designs (Keil et al., 2008). Researchers have typically focused on ssVEP amplitude and latency, comparing amplitude averages within a latency window of interest across conditions (Kemp et al., 2002; Silberstein, 1995). However, due to the sustained nature of the ssVEP signal, which can persist for a considerable duration (e.g., 9 s), EEG data can be processed and analyzed with significant temporal flexibility. This characteristic, along with other preprocessing variability, has spurred recent efforts among researchers to establish standardization and guidelines for the processing and analysis of EEG data (refer to Keil et al., 2014).

Functional Magnetic Resonance Imaging (fMRI) Studies

While the current work uses EEG as its primary metric, it is important to acknowledge the relevance of reviewing video research utilizing functional magnetic resonance imaging (fMRI) methodology in the study of emotions. Although the focus of this project is not on such research, examining the findings and methodologies employed in video studies with fMRI provides valuable context and insights into the understanding of emotional responses. Research employing fMRI has played a crucial role in investigating the emotional impact of various stimuli, including videos, and has helped elucidate the potential neuronal generators underlying emotional reactivity across different modalities. The fMRI technique uses the blood-oxygen-level-dependent (BOLD) signal, which relies on the increased oxygen consumption resulting from the activation of brain tissue, leading to overcompensation by the blood-flow response

(Plassman et al., 2007). Thus, during neuronal activation, deoxygenated hemoglobin is replaced partly by oxygenated hemoglobin, which results in increased signal activity that can be tracked with MRI (Huettel et al., 2009).

Most commonly, researchers have compared the BOLD responses to emotional still images or sounds and to neutral stimuli. Several studies have also combined affective sounds and images and have employed fMRI to explore the neural correlates via the hemodynamic response of emotional processing during video viewing (Byrge et al., 2022; Eldar et al., 2007; Goldberg et al., 2014; Goldin et al., 2005; Jääskeläinen et al., 2008; Karama et al., 2011; Nanni et al., 2018; Raz et al., 2012). These investigations have shed light on the brain regions and networks involved in emotional responses to videos and still images, thereby enhancing our understanding of the emotional impact of dynamic visual stimuli (Nanni et al., 2018).

The amygdala has emerged as a prevalent brain structure in studies examining both modalities (Hartling et al., 2021). Studies have consistently demonstrated increased amygdala activation when stimuli include affective words or vocalizations compared to neutral stimuli (Fecteau et al., 2007; Gao et al., 2020; Klinge et al., 2010). In the context of still images or pictures, extensive research has demonstrated reliable amygdala activation for emotional faces and scenes (Aldhafeeri et al., 2012; Lindquist et al., 2016; V. I. Müller et al., 2018; Sabatinelli et al., 2011; Whalen & Davis, 2009). Notably, the greatest overlap in amygdala activation has been documented between images containing faces or scenes (Sabatinelli et al., 2011). Activation of the amygdala has also been observed in response to emotional videos (Eldar et al., 2007; Raz et al., 2012), reflecting similar processes to those involved in affective responses to sounds and still images (Nanni et al., 2018). However, there remains some debate regarding the reliability of amygdala activation for auditory stimuli compared to visual stimuli (Buchanan et al., 2000; Schirmer et al., 2008).

Other relevant neuronal structures involved in visual processing include the medial prefrontal cortex and extrastriate occipital cortex (Sabatinelli et al., 2011). Additionally, reactions of the dorsal attention network (DAN) and default mode network (DMN) have been observed in response to emotional videos, reflecting the intricate interplay between attentional and self-referential processes during emotional experiences (Nanni et al., 2018).

These studies have also highlighted the importance of considering the temporal dynamics and distributed nature of emotional processing during video viewing. Emotional experiences elicited by videos have been shown to involve complex contextual information and to exhibit evolving temporal profiles distinct from the relatively static nature of emotional responses to static images (Goldberg et al., 2014; Goldin et al., 2005). The engagement of multiple functional networks, including sensory, association, limbic, and prefrontal cortical areas, underscores the integration of sensory, emotional, and cognitive information during emotional experiences with videos (Karama et al., 2011; Goldberg et al., 2014).

Overall, although the present study does not employ fMRI, it is essential to acknowledge the valuable insights provided by previous fMRI studies investigating the emotional impact of videos. These investigations have deepened our understanding of the neural underpinnings of emotional processing during video viewing and have shed light on the associated brain regions, networks, temporal dynamics, and the distributed nature of emotional experiences associated with videos.

Hypotheses

The aim of this study is to compare the emotional effects of still images and videos in the brain using EEG methodology. Specifically, we will investigate the differential neural responses elicited by emotional stimuli compared to neutral stimuli using two different EEG techniques: event-related potentials (ERPs) and steady-state visually evoked potentials (ssVEPs). We will utilize the traditional ERP method with pictures and the ssVEP method with videos, given the inherent dynamic nature of videos. The ssVEP technique is uniquely equipped to measure emotional responses in dynamic stimuli like videos. Traditional ERP methods struggle to account for the variable temporal characteristics of videos, making the analysis potentially inaccurate. In contrast, ssVEPs can accommodate the continuous and evolving stimuli presented in videos, ensuring more reliable and nuanced insights into emotion processing.:

H1. The emotional effects of pictures, as measured by ERPs, will differ from neutral stimuli. Emotional still images will elicit greater amplitudes in the late positive potential (LPP) component compared to neutral still images.

H2. The emotional effects of videos on the brain, as measured by ssVEPs, will differ from neutral stimuli. Emotional videos, as measured by ssVEPs, will exhibit lower amplitudes compared to neutral videos. This reduction in amplitude for emotional videos is attributed to the video-border competition. Specifically, when viewing emotional content, it is theorized that the brain redirects some cognitive resources towards processing the emotional components of the videos. This shift in attention, or cognitive resource allocation, results in attenuated EEG signals for emotional videos compared to neutral ones, reflecting a distinctive emotional effect.

H3. Additionally, the emotional effects of pictures, as measured by ERPs, will differ from neutral stimuli. Specifically, emotional (pleasant and unpleasant) pictures will elicit larger amplitudes in the early posterior negativity (EPN) component compared to neutral pictures.

H4. There will be a discernible within-subject relationship between the modulations of LPP and ssVEP. This relationship will elucidate whether both measures reflect the same underlying cortical process or if they denote distinct neural mechanisms.

Given the limited research that has directly compared still images and videos using central psychophysiological measures, it is important to consider potential outcomes to gain a comprehensive understanding of the differential emotional effects of the two modalities. On the one hand, the dynamic nature of videos provides more sensory stimulation and could, consequently, capture attention more effectively than pictures. The audiovisual elements and temporal unfolding of events in the videos could enhance emotional engagement and elicit stronger physiological responses. On the other hand, the inclusion of neutral videos may introduce additional sources of interest in unpredictability, thus potentially diluting the emotional effects seen in the emotional videos and resulting in smaller effects sizes. By exploring these possibilities, this study aims to produce novel insights into the nuances of emotional processing in response to different modalities.

CHAPTER 2

METHODS

Power Analysis

To ensure that our study was adequately powered to detect anticipated effects, a priori power analysis was conducted based on effect sizes observed in previous research. Prior research suggested an effect size of η^2 = .145 would be appropriate (Hajcak et al., 2013; Sabatinelli et al., 2023). Using this effect size as a guideline, G*Power program was utilized to determine the necessary sample size to achieve a power of 0.80, assuming a conventional alpha level of 0.05. Analyses indicated that to achieve 80% power, a minimum sample size of 30 participants would be required. Given that a paradigm of this nature has not been previously employed, the inherent unpredictability warranted a more cautious approach in participant recruitment. A larger sample size provides a buffer for the unpredictability of a new paradigm and ensures reliability in detecting neurophysiological differences.

Stimuli

A total of 180 stimuli (90 videos and 90 pictures) were utilized in this study and encompassed three distinct categories, representing content that spanned from pleasant to neutral and unpleasant, with varying levels of arousal. Within the pleasant stimuli category, content ranged from highly arousing scenes such as erotica to low-arousal scenes featuring children playing in a creek. The neutral stimuli encompassed mundane activities, all deliberately chosen to elicit equal levels of arousal, including scenarios such as grocery store visits and walking through cities. The unpleasant stimuli category encompassed content such as car crashes, which induced high arousal, as well as low-arousal scenes depicting teeth-cleaning procedures. Careful consideration was given to selecting stimuli that achieved a balance in terms of valence and arousal.

The videos were sourced from amateur platforms such as YouTube and Tumblr, following specific criteria to ensure consistency across categories. Each video was required to be 10 s long, maintain a singular viewpoint, have landscape orientation, and have no overlaid music or professional editing. To ensure uniformity and control over low-level visual and auditory features, all the videos were adjusted to maintain a consistent resolution (960 x 540 pixels) and a rate of 24 frames per second (FPS). Additionally, the videos were balanced for brightness (average luminance across 10-s duration), movement (average pixel movement between frames), and audio characteristics (similar decibel levels). Original videos that were too bright or had a different resolution or FPS rate were adjusted to equal values with Python's MoviePy library (Middya et al., 2022). Analyses of variance (ANOVAs) between emotional categories verified that all videos were equivalent ($p > .2$) across these low-level features.

To maximize experimental control, individual frames from the videos were used to assemble the pictures for the study, except in five cases where specific frames did not accurately represent the composition of the 10-s video. In those instances, suitable alternative photos were selected (unpleasant = 3; pleasant = 2; see Figure 1 for example). The pictures were standardized to a resolution of 960 x 540 pixels and maintained or downgraded to 90% JPEG quality with the GNU Image Manipulation Program (GIMP; http://www.gimp.org/). To ensure consistency, measures of luminance and complexity were conducted, using ANOVAs with p values greater than 0.2. For excessively bright scenes, adjustments were made with GIMP. To assess the complexity of the scenes, file sizes of the JPEG images at 90% quality were examined, as this has been shown to be a reliable measure in human perception studies (Donderi, 2006). In cases of overly complex scenes, a Gaussian blur technique was applied to the pictures. This technique, implemented through the OpenCV library in Python (Puri et al., 2018), has been shown to effectively reduce high-frequency details and smooth the image while maintaining the overall content but exert negligible impact on the perceived sharpness of the visual content.

Stimulus Manipulation

The current study aimed to address an observation identified in prior research, which suggested a significant electrocortical spike during the transition from a grey intertrial screen to video content (Sabatinelli et al., 2023; see Figure 2). The researchers hypothesized that this spike might be attributable to the sudden transition from an empty grey screen to vibrant video content. To mitigate this abrupt transition, a twofold procedure was implemented in the study involving frame scrambling and a ramping procedure. First, random frames from the videos were extracted based on a predetermined duration ranging from 2 to 4.5 s. Within each of these frames, all pixels were randomly rearranged and reassembled, resulting in a scrambled frame. Importantly, this scrambling process maintained the visual information of the original frames, including color and movement, while still creating uninterpretable content. During the scrambling phase, accompanying white noise was implemented for the same duration as the presentation of scrambled frames. Furthermore, to create a more gradual transition and eliminate the potentially overwhelming sensory response, a ramping procedure was developed. Across a duration of 12 frames (0.5 s), a smooth merge was applied between the scrambled frames (visual) and the accompanying white noise (audio). More specifically, the visual information from the scrambled frames and the actual video frames were transformed into numerical values, creating a gradient percentage between the scrambled frames and the real frames. This percentage gradually shifted across all 12 frames, with a slow progression towards 100% representing the real frames and 0% representing the scrambled frames. A similar process was applied to the audio by replacing the white noise with audio noise and applying the same gradual transition. Once the real frames reached 100%, a trigger was sent to the EEG data collection machine. This gradual blending allowed for a progressive shift from the initial scrambled frames to the actual video frames, accompanied by a corresponding transition from white noise to the original audio. By gradually introducing the visual and auditory stimuli and avoiding sudden shifts, we aimed to provide participants with a more comfortable and seamless experience, thereby reducing the initial magnitude of the electrocortical response observed in Sabatinelli et al.'s (2023) study.

Procedure

After the informed consent form was signed, participants were brought into an electrically shielded chamber for EEG recording. Participants were fitted for the appropriate EEG cap and asked to sit in a chair 41 inches from the monitor in a darkened electromagnetically shielded room. All stimuli were presented on a 28-inch, 60Hz, monitor, resulting in a 21-degree viewing angle. Participants were exposed to the stimuli in four distinct viewing paradigms, characterized by the combination of two factors: the order of presentation (either pictures first or videos first) and the predetermined sequence of emotional content (order A or order B). These paradigms included "A_pics" (order A with pictures presented first), "B_pics" (order B with pictures presented first), "A_vids" (order A with videos presented first), and "B_vids" (order B with videos presented first). To ensure balanced and varied exposure, the stimuli within each order presentation (A and B) were pseudorandomly organized, ensuring that no emotional content (unpleasant, neutral, or pleasant) was consecutively presented more than four times in a row. As depicted in Figures 3 (video) and 4 (pictures), videos were presented to participants for

12–14.5 s, with uniform 2-s intertrial intervals (i.e., grey screen), and pictures were presented for 2 s, with intertrial intervals between 1.5–2.5 s. After each switch in stimuli paradigms, such as transitioning from viewing videos to pictures or vice versa, a brief intermission was provided to allow for necessary logistical tasks. During this intermission, participants were given a momentary break to stretch while remaining seated, and researchers created a new save file to ensure proper data recording. This intermission served as a transitional period before proceeding with the next set of stimuli.

EEG Acquisition

To evoke a steady-state response, a 14-inch black border was presented in rapid alternation, which created a 7.5-Hz flicker surrounding the video. Participants were instructed to minimize blinking during the stimulus presentation and to wait for the intertrial interval (i.e., grey screen) to blink when possible. Continuous EEG data were recorded with a 128-channel BioSemi ActiveTwo system (BioSemi, Amsterdam, Netherlands) with preamplified electrodes positioned according to the 10-20 layout, with midline electrodes (CMS and DRL) used as a reference. Data were acquired at a sampling rate of 512 Hz using the ActiView software (actiview.org) to maintain offsets between 50 to −50 millivolts during EEG setup and to monitor online data acquisition. The entire EEG viewing session took approximately 35 min.

Stimuli Self-Reports

After the EEG session, participants self-reported the valence and arousal of each scene on a 9-point scale using the SAM (Bradley & Lang, 1994). Participants were seated in a quiet room, and instructions on how to use the SAM scale were read to them. Participants then viewed a nonscrambled and nonflickering version of the videos and pictures on a computer monitor using

Qualtrics software. Due to time constraints, participants were told that they were not required to watch the full video, just however long they needed to make their selection.

EEG Reduction and Analysis

For the ssVEP analysis of video data, EEG data were preprocessed and segmented with the Electro Magnetic Encephalography Software (EMEGS; emegs.org) analysis package in MATLAB (MathWorks, Natick, MA, USA). To control for high-frequency noise, the data underwent bandpass filtering with a low-pass Butterworth filter with a stopband of at least 40 Hz and a passband of 30 Hz. Additionally, a high-pass Butterworth filter with a stopband of 1 Hz and a passband of 3 Hz was applied. Trials with excessive noise (< 2%) were excluded. A phase-shifted version of the empirical signal was generated using the Hilbert transformation implemented in MATLAB, and the time-varying amplitude was extracted. The ssVEP signal was extracted between 1000 ms and 9000 ms post-trigger, with no baseline correction. The channels used for ssVEP analysis were O1, POO1, OI1H, Oz, Iz, POO2, O2, and OI2H.

For the event-related potential (ERP) analysis of picture data, EEG data were preprocessed and segmented with the EMEGS analysis package in MATLAB. Data were bandpass filtered using a low-pass Butterworth filter with a stopband of 40 Hz and a passband of 30 Hz to control for high-frequency noise. Additionally, a high-pass Butterworth filter with a stopband of 0.05 Hz and a passband of 0.1 Hz was applied. Segmentation was performed from 100 ms before scene onset to scene offset, which occurred after 2000 ms. The 100 ms of data before scene onset were used to baseline the ERPs. The early posterior negativity (EPN) was measured by extracting voltage from electrodes PPO9h, PO7, PO9, POO9H, PPO10h, PO8, PO10, and POO10h from 150–300 ms after picture onset. The late positive potential (LPP) was recorded over electrodes CCP1h, CP1, CPz, B12, Pz, D4, CP2, and CPP2h from 400–900 ms after picture onset.

Participants were excluded if their number of good trials was two standard deviations (7.92) lower than the set average of 50.44 good trials for the video portion of the study. Both data sets were further processed with an average reference transformation (Peyk et al., 2011). Artifacts were identified through an automated analysis in EMEGS that utilized median values of maximum amplitude, standard deviation, and maximum first derivative to detect unusable trials and unreliable electrodes. Contaminated sensors were replaced with values calculated through spherical spline interpolation, where the least noisy and closest electrodes contributed the most to the new replacement amplitude. Once the data preprocessing steps were completed, ERPs and ssVEP responses were extracted for each scene for each participant, and the mean responses over the designated time windows were calculated.

Statistical Procedure

To assess the differential emotional responses between ERPs and ssVEPs, comparative statistical analyses of the average responses within the relevant time windows for each emotional category were conducted. The variations between emotional and neutral stimuli across the ssVEP and ERP methods were the general focus of the analyses. These analyses aimed to identify and compare the magnitudes of differences in emotional elicitation between pictures (ERPs) and videos (ssVEPs).

The first analysis involved performing separate repeated-measures ANOVAs for the EPN, LPP, and ssVEP data. Significant emotional differences were observed, and effect sizes were calculated using generalized eta squared (η^2) to quantify the proportion of variance explained by each effect. Effect sizes were compared across ANOVAs to obtain an estimate of the strength of emotional elicitation. These analyses were conducted using RStudio and the rstatix package (Kassambara, 2021). The results provided insights into the differences in emotional response across the three emotional categories for each modality.

In the second analysis, z-scores were calculated for the EPN, LPP, and ssVEP values across all participants and emotional categories. These z-score values were then combined and analyzed through a repeated-measures ANOVA. This analysis provided a comprehensive assessment of the overall emotional effect, allowing for direct comparisons between the modalities. The results revealed any significant differences between pictures and videos in eliciting emotional responses.

The third analysis involved correlating the EPN, LPP, and ssVEP values with the self-reported arousal ratings provided by participants through the SAM. Pearson correlation coefficients were calculated to determine the strength and direction of relationships. This analysis provided insights into which modality had the strongest correlation with self-reported arousal, thereby indicating the effectiveness of each modality in eliciting emotional responses. The statistical procedures described above aimed to assess and compare the emotional effects of pictures and videos. Separate repeated-measures ANOVAs were conducted, z-score values were combined and analyzed, and correlations with self-reported arousal were examined. These analyses provided a comprehensive understanding of the emotional response across different modalities and offered valuable insights into the effectiveness of pictures and videos in evoking emotional experiences.

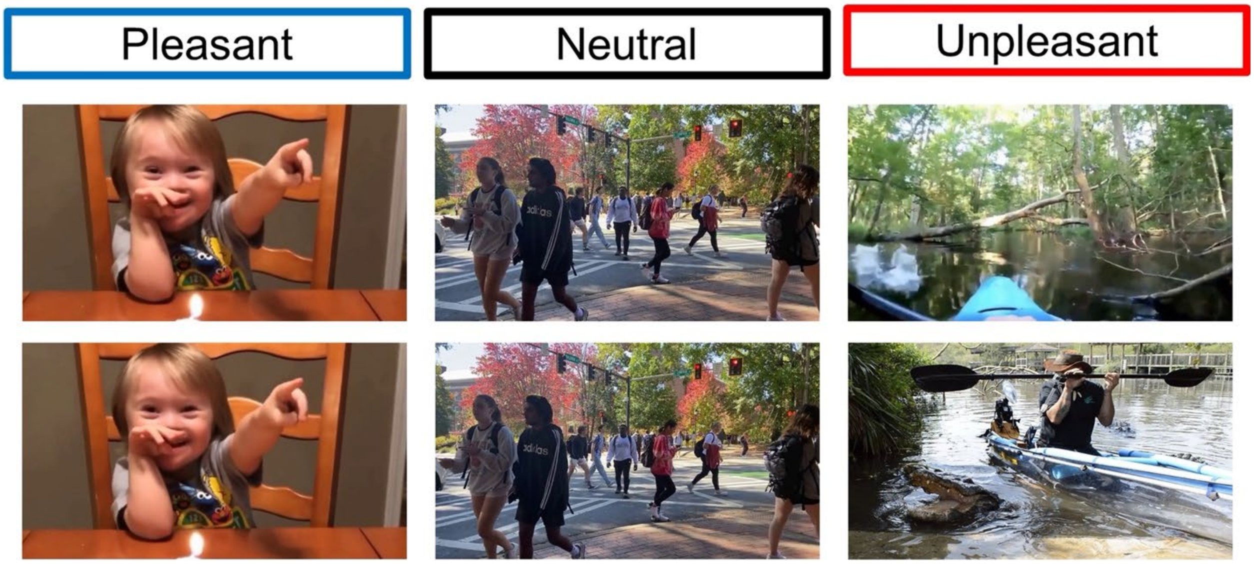

Figure 1. Scene examples from each emotional category. From left to right, images depict representative scenes from the pleasant, neutral, and unpleasant emotional categories. The top row represents the videos, while the bottom row highlights corresponding frames used for the emotional pictures. Notably, the image in the unpleasant column at the bottom demonstrates an instance where the selected picture was not directly derived from a frame of its corresponding video.

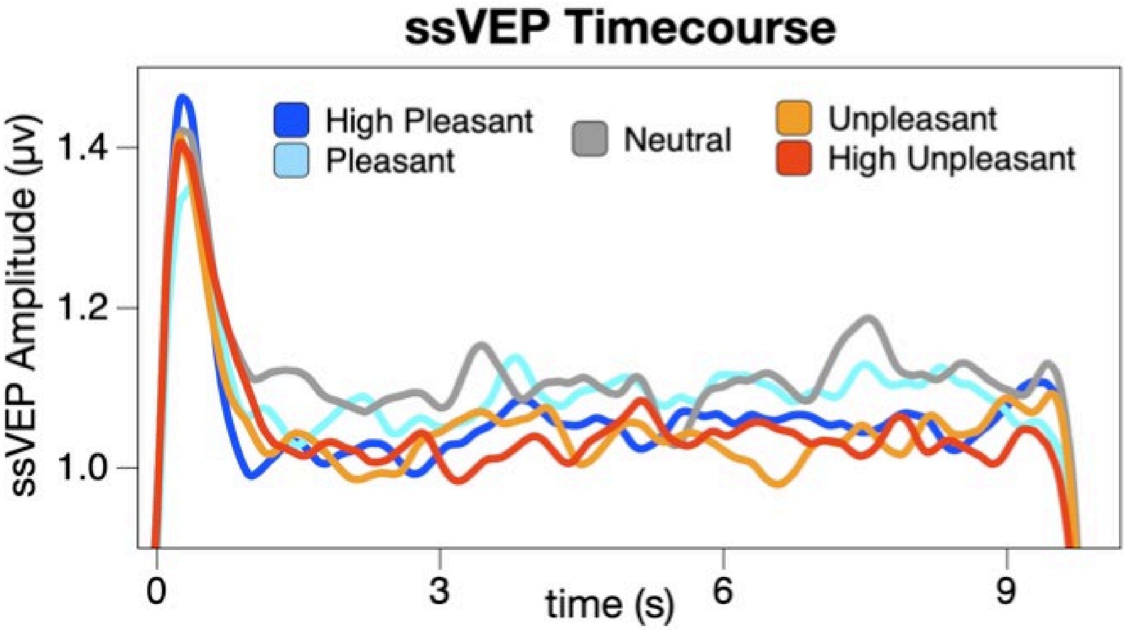

Figure 2. Average waveforms of recent ssVEP video study. As can be seen there is a large spike in activity immediately following the presentation of the video. This spike was attempted to be mitigated through a twofold scrambling procedure.

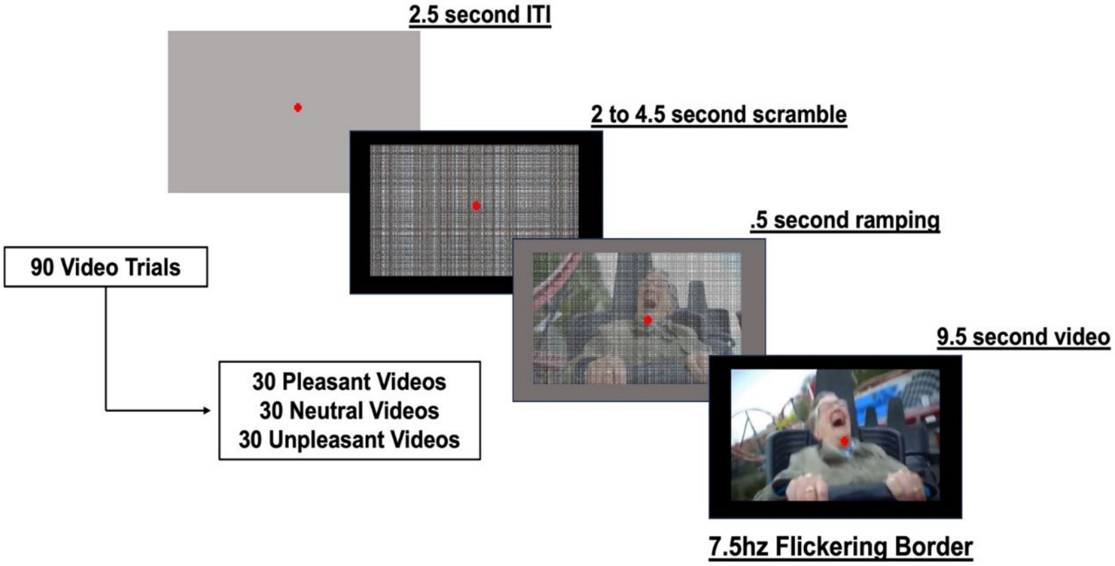

Figure 3. ssVEP paradigm. Participants viewed 90 pleasant neutral and unpleasant videos for between 12-14.5s while a flickering border (7.5Hz) to evoke a steady-state response for the duration of the video. Trials were separated by an inter-trial interval of 2.5 seconds.

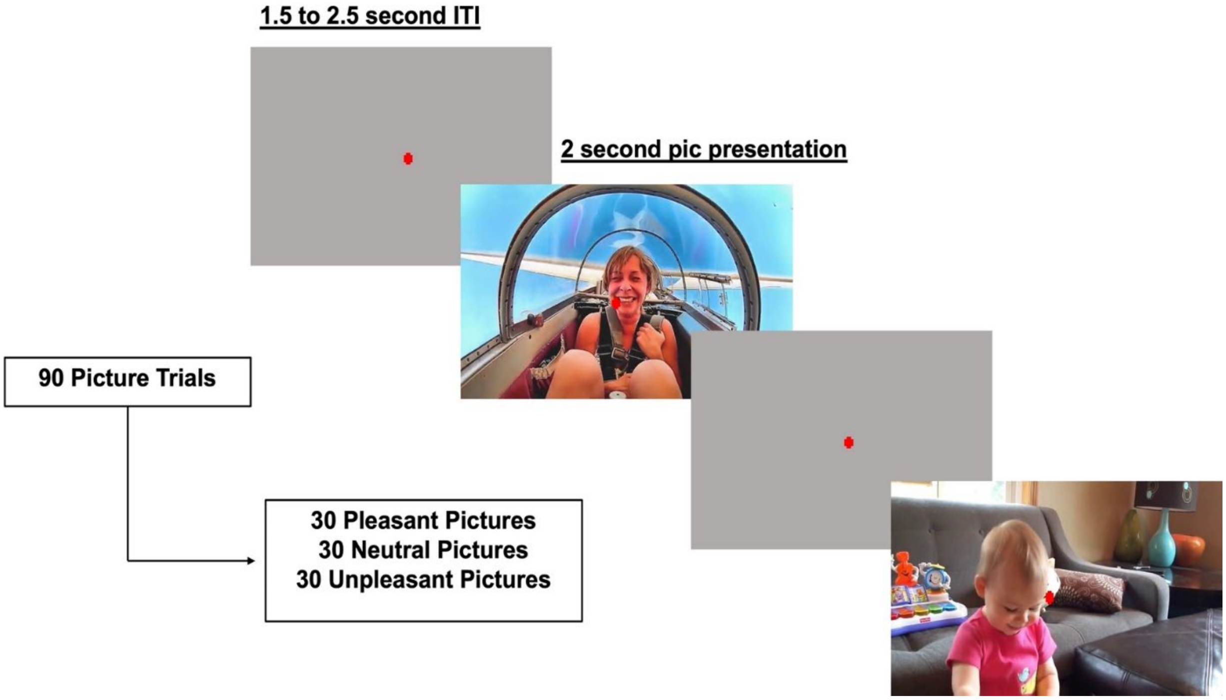

Figure 4. ERP paradigm. Participants viewed pleasant neutral or unpleasant pictures for 2s. Trials were separated by a variable inter-trial interval of 1.5-2.5s.

CHAPTER 3

RESULTS

Participants

Fifty participants were initially recruited from the University of Georgia (UGA) undergraduate student body and were compensated with course credit for their participation. However, two participants were ultimately excluded from the analysis. During data collection, one participant's electroencephalogram (EEG) data file became corrupted due to a computer crash, resulting in the loss of their data. Another participant chose to withdraw from the experiment after being exposed to the first round of stimuli. The remaining participants (n = 48) were between the ages of 18 and 21 (*M* = 19.04, *SD* = 1.02), with 32 identifying as female and 16 as male. Most participants reported a "Caucasian/White" racial/ethnic identity (62.50%), though "African American/Black" (4.17%), "Asian/Asian American" (14.58%), "Latino/Hispanic" (6.25%), Indian" (4.17%), "Middle Eastern" (2.08%), and "Multiracial" (4.17%) were also reported. Before the EEG session began, all participants were informed that they would not be allowed to participate if they had a diagnosis of epilepsy. All participants gave informed consent after reviewing a form approved by the UGA Human Subject Institutional Review Board (IRB).

Scene Stimulus Ratings: Emotional Differences

A 2-way repeated measures ANOVA was conducted separately for self-reported arousal and valence ratings, with emotional category (pleasant, neutral, and unpleasant) and stimulus type (pictures and videos) as within-subject factors. Arousal and valence ratings of the stimuli are shown in Figure 5. In alignment with the study design, significant differences were observed in both valence and arousal across emotional categories (valence: $F(2,94) = 388.71$, $p < .001$, $\eta^2_G = .84$; arousal: $F(2,94) = 112.13$, $p < .001$, $\eta^2_G = .57$).

As expected, pleasant (M = 5.52, SE = .05) and unpleasant (M = 6.58, SE = .04) pictures had significantly higher arousal (pleasant: $t(48) = -7.17$, $p<.001$, d = -1.04; unpleasant: $t(45) = -11.05$, $p< .001$ d = -1.60) compared to neutral pictures (M = 4.15, SE = .04). Likewise, the comparisons for videos showed similar trends for pleasant (M = 5.99, SE = .05) versus neutral ($t(48) = -10.37$, $p<.001$, d = -1.49) and unpleasant (M = 6.82, SE = .04) versus neutral (M = 4.18, SE = .04; $t(48) = -14.01$, $p<.001$, d = -2.03) videos. Interestingly, arousal ratings for unpleasant videos ($t(48) = -6.68$, $p < .001$; d = -.96) and pictures ($t(48) = -7.30$, $p < .001$; d = -1.05) were significantly higher than pleasant videos and pictures.

Similarly, valence ratings suggest that pleasant (M = 6.51, SE .05) and unpleasant (M = 3.33, SE = .04) pictures were significantly different (pleasant: $t(48) = -13.13$, $p<.001$, d = -1.89; unpleasant: $t(48) = 14.88$, $p<.001$, d = 2.15) compared to neutral pictures (M = 5.23, SE = .02). Valence ratings also suggest that pleasant (M = 6.66, SE = .05) and unpleasant (M = 3.30, SE = .05) videos are significantly (pleasant: $t(48) = -14.68$, $p< .001$, d = -2.11; unpleasant: $t(48) = 15.46$, $p< .001$, d = 2.23) different compared to neutral videos (M = 5.31, SE = .03). Following an expected pattern, pleasant pictures (M = 6.51, SE = .05) and videos (M = 6.66, SE = .05) had significantly higher valence ratings (pictures: $t(48) = 21.95$, $p<.001$, d = 3.17; videos: $t(48) = 26.13$, $p<.001$, d = 3.77) compared to unpleasant pictures (M = 3.33, SE = .04) and videos (M = 3.30, SE = .05).

Scene Stimulus Ratings: Stimuli Type Differences

An arousal effect was observed comparing arousal scores between videos and pictures (*F*(1,47) = 23.05, *p*<.001; η^2_G = .018) with pleasant (*t*(48) = -6.55, *p*<.001, d = -.946) and unpleasant (*t*(48) = -4.20, *p*< .001, d = -.607) videos having a higher self-reported arousal compared to the pleasant and unpleasant pictures. There was no significant difference between neutral videos and neutral pictures (*p* = .82). The valence ratings show no significant differences between pictures and videos for neutral (marginal p = .06) and unpleasant (p = .49) emotional categories. However, there was a significant difference between pleasant pictures and videos (*t*(48) = -2.85, *p* = .006, d = -.411) with pleasant videos (M = 6.66, SE = .05) having slightly higher valence ratings compared to pleasant pictures (M = 6.51, SE = .05).

Physiological Results by Emotional Category

ssVEP, LPP and EPN waveforms across participants and scene category are shown in figure 6. Separate ANOVAs revealed that each physiological measure significantly differed as a function of emotional category (LPP: *F*(2,94) =45.54, *p*<.001, η^2_G = .215; EPN: *F*(2,94) = 14.77, *p*<.001; η^2_G = .024; ssVEP: *F*(2,94) = 44.30, *p*<.001; η^2_G = .017). LPP modulation was greater for pleasant (M =1.22 µV, SE = .29; *t*(48) = -7.43, *p*<.001, d = -1.07) and unpleasant (M = 1.03 µV, SE = .28; *t*(48) = -7.84, *p*< .001, d = -1.13) pictures compared to neutral pictures (M = -1.02 µV, SE = .28). However there was no significant difference between pleasant and unpleasant pictures (*t*(48) = .93, *p* > .9). Similarly, ssVEP modulation was greater for pleasant (M = .98 µV, SE = .03; *t*(48) = 6.15, *p*<.001, d = .89) and unpleasant (M = .96 µV, SE = .03; *t*(48) = 7.96, *p*<.001, d = 1.15) compared to neutral videos (M =1.04 µV, SE =.04). Interestingly, a marginal difference between ssVEP amplitude during pleasant and unpleasant videos (*t*(48) = .93, *p* = .03), was observed. EPN modulation was greatest for pleasant (M = 10.27 µV, SE = .60) compared to neutral (M = .11.85, SE = .62; *t*(48) = 4.89, *p*<.001, d = .71) and unpleasant (M = 11.35 μV, SE = .62; *t*(48) = -4.04, *p*< .001, d = -.58), with neutral and unpleasant stimuli not yielding a significant difference (*t*(48) = 1.67, *p* = .3). Figure 7 shows categorical averages used in the analysis.

Correlation Analyses

In exploring the intricate associations among self-reported measures of valence and arousal, and the physiological metrics of LPP, ssVEP, and EPN, this study employed a dual-faceted approach anchored in both by-scene and by-participant correlations using z-scored values. For the by-participant correlations, the study delved into individual variations by examining how each participant's average self-report related to their physiological responses. Furthermore, it assessed the interrelationships among the physiological measures themselves, encompassing LPP, ssVEP, and EPN across all individual participants. Concurrently, the by-scene correlations were operationalized by evaluating the collective average of self-reports and each of the physiological measures unique to every discrete scene. This multi-dimensional approach aimed to understand both individual experiential variations and the distinct emotional and physiological responses elicited by each stimulus. A complete pairwise scatter plot of all correlations, associated Pearson R and p-values can be seen in figures 8 and 9.

A negative correlation characterized the relationship between LPP and ssVEP amplitude, supported by both by-participant (r = -.49, p<.001) and by-scene (r = -.35, p < .001) correlations. Likewise, the interrelation between LPP and EPN was similarly marked by a negative trend, confirmed by by-participant (r = -.26, p = .002) and by-scene (r = -.50, *p*<.001) correlations. However, the relationship between ssVEP and EPN was more nuanced, with only the by-scene correlations showcasing a positive association (r = .22, p = .03) and a marginal by-participant (r

= .16, p = .05) correlation. In essence, consistent correlations between ssVEP and LPP across varied analytical frameworks emphasize their shared roles in visual-emotional processing.

A deeper dive into the associations between physiological metrics and self-reported arousal unveiled consistent trends. The relationship between the ssVEP and self-reported arousal was consistently negative, as endorsed by both by-participant (r = -.64, p<.001) and by-scene (r = -.63, p<.001) correlations. Similarly, the LPP exhibited a positive association with self-reported arousal, backed by both by-participant (r = .54, p<.001) and by-scene (r = .52, p<.001) analyses. The relationship between the EPN and self-reported arousal was more variable, with only by-participant correlations indicating a weak negative association (r=-.20, p = .01), while by-scene correlations did not showcase any significant relation (p = .19).

These findings collectively elucidate the connection between physiological measures of emotional processing, both in dynamic videos and still pictures, and individuals' self-reported experiences of those emotions.

Comparing Physiological Responses

The overarching aim of this analysis was to delve into the comparative efficacy of ssVEP and LPP in discerning emotional responses across still images and videos. To facilitate a more nuanced comparison between these physiological measures, a two-pronged normalization approach was employed: First, the ssVEP values were multiplied by negative one, to align the directional response across both measures, thereby ensuring that any observed disparities are reflective of the measures' effectiveness rather than the inherent nature of the data. Data were then z-scored to accommodate the differences in scales between ssVEP and LPP amplitudes.

Normalized averages are shown in figure 7. A repeated measures ANOVA was conducted on the normalized values, with 'emotional category' and 'wave type (LPP and ssVEP) serving as independent variables. While a prior analysis had underscored a significant main effect of emotional category on each physiological measure, this further analysis was geared towards a nuanced comparison between ssVEP and LPP. The main effect reiterated that the emotional category (LPP: $F(2,94) = 49.03$, $p < .001$, $\eta^2_G = .511$; ssVEP: $F(2,94) = 49.07$, $p < .001$, $\eta^2_G = .511$) significantly modulated the physiological responses, thus emphasizing the sensitivity of both ssVEP and LPP in delineating emotional processing variances between still images and videos. However, there was no main effect of wave type and no significant interaction.

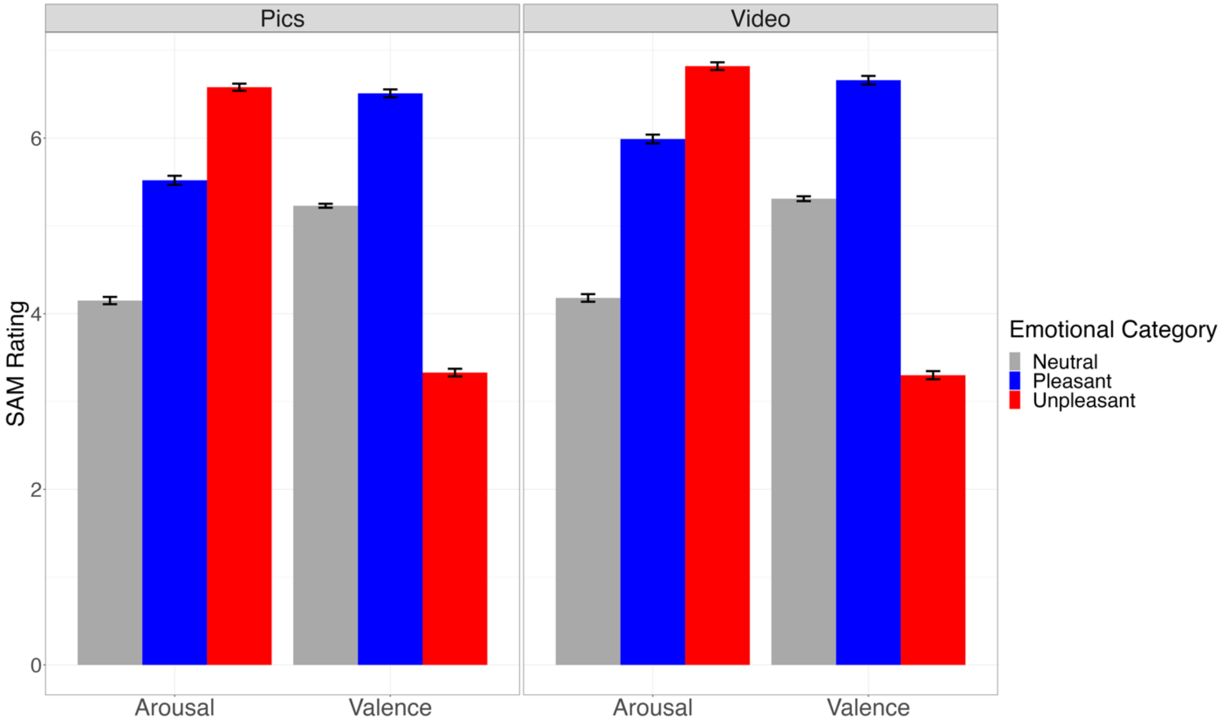

Figure 5. Self-report ratings for videos and pictures across emotional categories. Each color represents one of the emotional categories. Black bars indicate standard error.

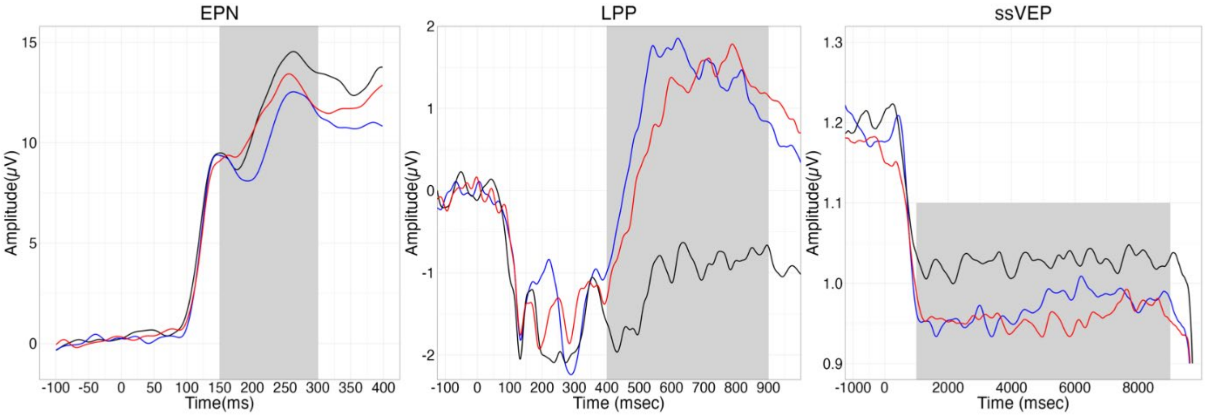

Figure 6. Waveforms across the sample. Pleasant: Blue; Neutral: Black; Unpleasant: Red. Shaded areas indicate the time epochs extracted for ANOVAs.

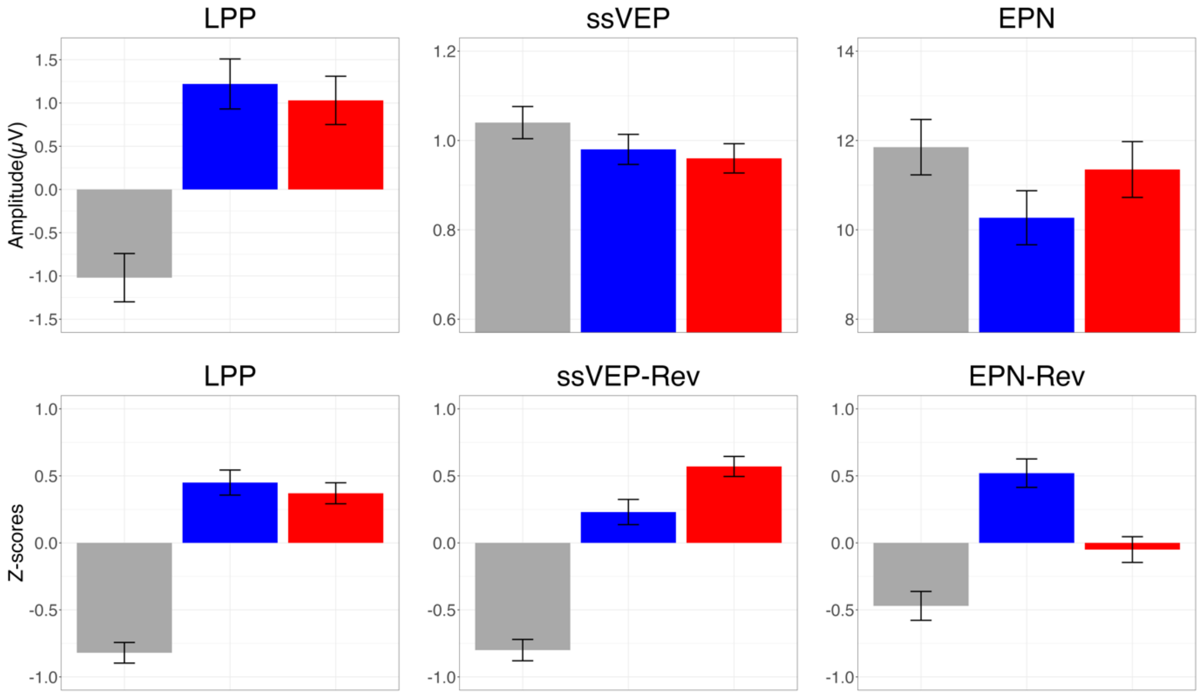

Figure 7. Extracted raw and z-scored results. Raw voltage data from each EEG measure is plotted first. To better visualize across the measures, which differ in range and timing, raw scores were transformed to z-scores. In addition, given the nature of the EPN and ssVEP, scores were reverted to allow for easier interpretation. Blue: Pleasant; Black: Neutral; Red: Unpleasant. Black bars indicate standard error.

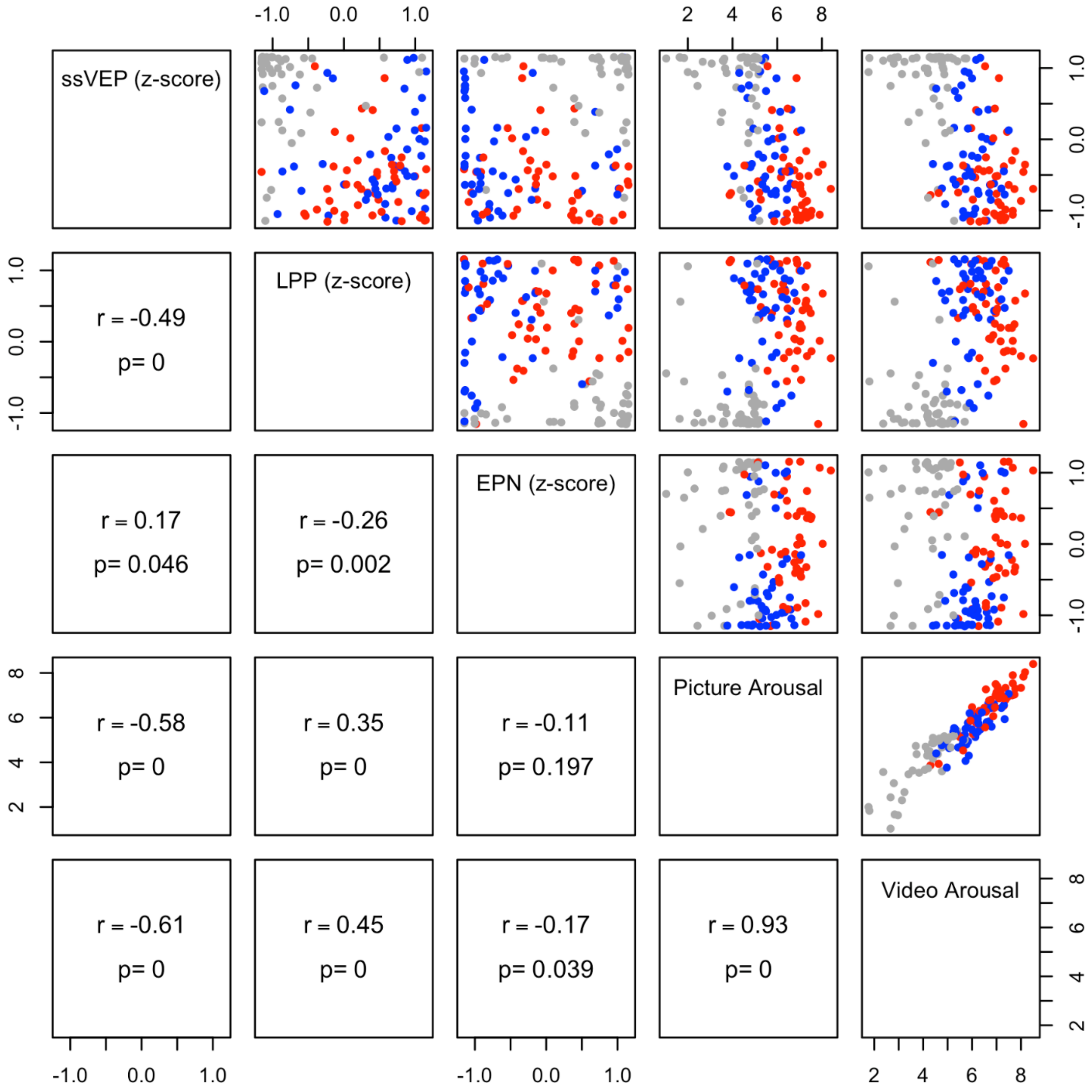

Figure 8. Pair-wise scatter plots for all 48 participants. Colors indicate the scene category. Each colored dot represents the categorical average for a participant. The Diagonal indicates the variable. For each row, the variable in that row acts as the dependent variable and is the y-axis. For each columns the variable acts as the independent variable. The lower panel indicates the coefficient and p-value of the associated correlation.

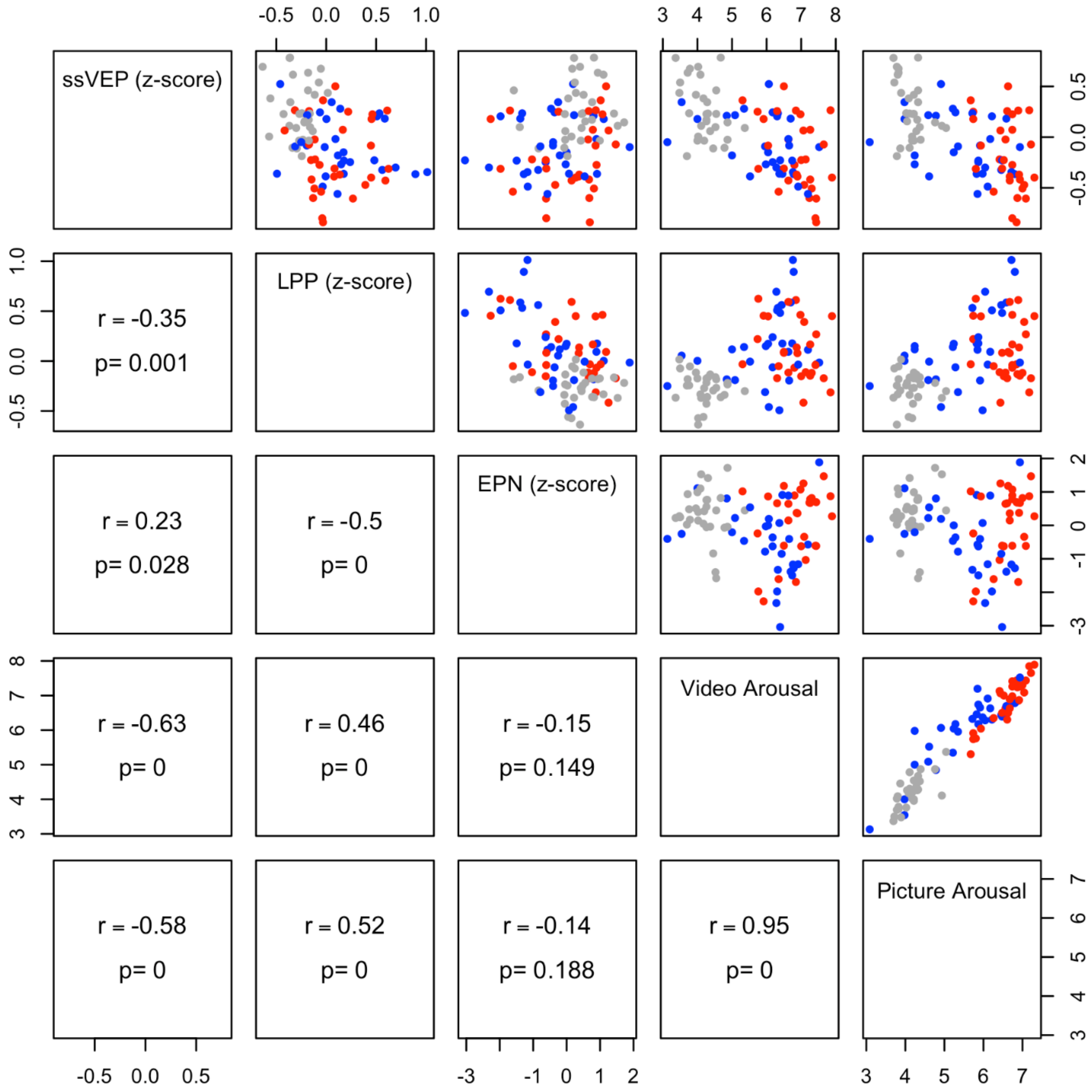

Figure 9. Pair-wise scatter plots for all 180 stimuli. Colors indicate the scene category. Each colored dot represents all averaged self-report ratings for that scene. The Diagonal indicates the variable. For each row, the variable in that row acts as the dependent variable and is the y-axis. For each columns the variable acts as the independent variable. The lower panel indicates the coefficient and p-value of the associated correlation.

CHAPTER 4

DISCUSSION

This study explored emotional responses utilizing diverse physiological methodologies, extending previous work that revealed enhanced ssVEP responses to emotional dynamic stimuli, notably videos (Sabatinelli et al., 2023). Concurrently, earlier findings have demonstrated that emotional static stimuli, such as pictures, modulate the LPP (Cuthbert et al., 2000; Schupp et al., 2007) and EPN (Junghöfer et al., 2006; Schönwald & Müller, 2014; Schupp et al., 2006), suggesting a broad physiological responsiveness to varied emotional media. A particular focus was placed on discerning whether emotional processing, reflected through ERPs in response to static stimuli (still images), exhibits congruence with ssVEPs elicited by dynamic stimuli (videos), thereby probing the consistency in neural mechanisms across distinct emotional media formats. To establish a robust comparison, stimuli presented to participants were carefully matched, employing frames from the videos as still images to ensure visual consistency across both static and dynamic conditions. Preliminary findings indicate a similarity in cognitive processes measured by ssVEP and the LPP. Category differences and relationships between physiological measures and their respective stimuli were quantified using repeated and between measures ANOVAs and paired t-tests. Additionally, relationships between physiological metrics and stimuli employed a dual approach: one centered on individual participants and another on scene-specific analyses, examining both personal variations and collective physiological responses to each scene.

Physiological Emotional Differences

Variation in the amplitudes of EPN, LPP, and ssVEP were observed in relation to emotional categories within the study. Specifically, a discernible amplification of voltage negativity in the EPN was prominent when subjects were exposed to pleasant scenes, as opposed to neutral and unpleasant scenes. This observation, aligned with existing research, indicates a tendency of the EPN to exhibit a bias towards pleasant stimuli (De Cesarei & Codispoti, 2006; Flaisch et al., 2008; Frank & Sabatinelli, 2019; Schupp, Cuthbert et al., 2004; Weinberg & Hajcak, 2010). Further analysis by Farkas et al. (2019) highlighted erotic scenes evoked larger EPN amplitudes than equally arousing victory scenes, and the EPN showed stronger modulation to nonerotic nude scenes over erotic scenes. This suggests the EPN's response is influenced both by the emotional intensity within visuals and the overt presence of exposed bodies (Farkas et al., 2019). Adding to this, Frank and Sabatinelli (2019) through their research, supplemented by fMRI measures, deduced that both erotic and joyful scenes induced an elevated EPN modulation compared to aversive mutilation scenes, hinting at the EPN's inclination towards highly arousing pleasant stimuli.

In sync with previous studies, our findings indicate that both pleasant and unpleasant images consistently led to enhanced LPP amplitudes when compared to neutral images (Bradley, 2009; Codispoti et al., 2006, 2007, 2012; Miskovic et al., 2015; Weinberg & Hajcak, 2010). Notably, while the modulation of LPP has been found to correlate with self-reported arousal ratings, specific content, like erotica or mutilation scenes, can evoke even larger LPP amplitudes than those expected based purely on arousal metrics (Weinberg & Hajcak, 2010). Such observations propose that content with evolutionary significance may uniquely influence the LPP, even when participants report similar arousal levels across various stimuli (Hajack et al., 2010; Lang & Bradley, 2010; Schupp et al., 2000). Our study, however, was limited in confirming this, due to the sparse subcategories of scenes available. Although there was a trend indicating erotic pictures leaning towards the expected direction, formal testing was precluded. Thus, while our current insights align with the broader understanding of LPP modulation by emotional valence, examining the role of specific content in LPP reactivity is a promising avenue for further research.

Modulation of the ssVEP was in line with previous research which shows the deprecated ssVEP responses for emotional compared to neutral pictures (Keil et al., 2005; Miskovic et al., 2015) and videos (Sabatinelli et al., 2023). By integrating a concurrent visual flicker, a continuous metric of non-instructed emotional engagement towards each video clip was obtained. Videos, with their rich and dynamic stimuli, necessitate multiple brain network engagements, facilitating perceptual processing spanning auditory and visual domains. This reduced ssVEP amplitude during emotionally charged content might reflect heightened activation across diverse sensory and associative regions in the brain. Such modulations could be driven by frontal cortical structures and, indirectly, by subcortical structures (Keil et al., 2009; 2012; Moratti et al., 2004).

Relationship Between Measures

The current study corroborates prior research (Cuthbert et al., 2000; Hamm et al., 2003; Schupp, Cuthbert et al., 2004; Schupp, Junghöfer et al., 2004) in delineating a consistent relationship between LPP amplitudes and self-reported arousal, evidenced both by-scene and by-participant correlations. While high-arousal stimuli like erotic or threatening images theoretically engage both appetitive and defensive motivational systems (Bradley and Lang, 2000; Lang et al., 1997b; Schupp, Cuthbert et al., 2004), current conclusions regarding these stimuli should be viewed with caution. They hinge on a noticeable visual trend rather than formal statistical testing due to an imbalance across the semantic conditions.

The arousal relationship is evident across varying stimulus presentation durations, from as brief as 120ms (Schupp, Junghöfer, et al., 2004) to as long as 6s (Cuthbert et al., 2000) suggests that our brains are proficiently equipped to swiftly and reliably identify both positive and negative reinforcers Such a capability likely evolved to promote adaptive behaviors integral to survival and reproductive success (Schupp, Junghöfer, et al., 2004). Supporting this notion are measures of sympathetic nervous system arousal, such as skin conductance (Braithwaite et al., 2013). Emotionally charged IAPS images known to spur heightened arousal consistently trigger more accentuated skin conductance responses and are typically perceived as more captivating (Bradley and Lang, 2000). This attests to the idea that stimuli with profound emotional potency, by their intrinsic motivational relevance, gain precedence in the brain for prolonged attention and thorough processing (Lang et al., 1997).

ssVEP amplitudes exhibited a negative correlation with self-report measures in both by-scene and by-participant analyses. Prior research using paradigms that generate ssVEP responses to emotional static images has demonstrated associations between ssVEP amplitudes and self-report arousal ratings (Bekhtereva et al., 2015; Keil, 2008). Beyond the EEG literature, investigations have shown that emotional videos correspond with SAM arousal ratings across various peripheral physiological indicators such as skin conductance (Aguado et al., 2018; Fernandez et al., 2012), facial electromyography (Aguado et al., 2018), and heart rate (Fernandez et al., 2012).

A recent study employing ssVEP methodology with videos established a robust correlation between SAM arousal ratings and ssVEP amplitudes (Sabatinelli et al., 2023). The current approach differs from traditional ERP investigations, which typically rely on brief image presentations and millisecond post-presentation analyses. In contrast, the current focus captures the physiological response across a prolonged eight second window. This sustained relationship with self-report metrics suggests the ability of ssVEP responses to authentically reflect the subjective narrative experience from start to finish. Consequently, it accentuates the prospect of ssVEPs emerging as a significant, temporally consistent marker of physiological arousal.

Contrary to previous findings (Hajack et al., 2013; Miskovic et al., 2015; Schönwald & Müller, 2014), the current study observed significant correlations between ssVEP and LPP amplitudes. However, it should be noted, that Schönwald and Müller (2014) reported a near-significant ($r = -.38$, $p = .009$) relationship. One pivotal distinction is in the divergence of stimulus modality and duration between the current investigation and previous studies. Earlier studies primarily relied on static images with shorter exposure times (Hajack et al., 2013: 6000ms; Miskovic et al., 2015: 2971ms; Schönwald & Müller, 2014: 4533ms). In contrast, the current study explored emotional processing through a dynamic and temporally extended modality. This variation in stimulus characteristics and duration could explain the interconnections between ssVEP and LPP amplitudes. Specifically, the ssVEP, indicative of lower-tier visual cortical responses (Keil et al., 2009) and the LPP, reflecting later attentional processes (Bradley, 2009), may operate in closer harmony when faced with the evolving emotional content in videos. Notably, this synchrony implication is further substantiated by significant correlations observed at both the by-participant and by-scene levels of data. Thus, such coordination potentially signifies a dynamic interplay between early sensory and subsequent attentional/semantic neural processes, enabling observers to dynamically engage and adapt to the evolving emotional narratives presented across different mediums.

Static vs. Dynamic Emotional Media

The use of frames extracted directly from the videos as still images attempted to ensure the utmost visual consistency between the two conditions. This design strategy attempted to minimize potential discrepancies in the visual content that could influence physiological responses and, by extension, the subsequent interpretations of any observed differences between static and dynamic stimuli. The physiological correlations between self-report measures and the ssVEP and LPP responses suggest that similar cognitive mechanisms are at play, regardless of whether the emotional stimulus is static or dynamic. Both formats appear to engage the emotional processing centers of the brain in a consistent manner, indicating that the brain’s core systems for emotion recognition and response are broadly adaptable to varied media formats.

Additionally, the synchrony observed between LPP and ssVEP can be interpreted as an indication of their interlinked neural underpinnings. While both these measures provide insights into emotional processing, their concurrent activation in response to both static and dynamic stimuli suggest a shared neural foundation. This foundation warrants further exploration, potentially providing a roadmap for future studies aiming to decipher the intricate neural networks underpinning our emotional responses to varied media.

Limitations and Future Directions

A notable limitation of this study pertains to the absence of distinct semantic categories. Traditional ERP studies have benefited from the use of stimuli meticulously classified into distinct semantic groups such as erotica and mutilations, a systematic approach that was not fully implemented in the present study. With the established content in this research only partially aligning with these recognized categories, a balanced representation was not achieved. This lack of formalized semantic categorization might have restrained our ability to powerfully discern the nuanced ways different types of content influence the correlation between ssVEP and LPP amplitudes. Notably, the LPP's known sensitivity to the arousal level of stimuli, especially within the domains of erotic and mutilation content (Weinberg & Hajcak, 2010), could be pivotal in further delineating the emotional processing landscape. Prior research employing ssVEP methodologies with video stimuli has suggested a nuanced trend: highly arousing stimuli, regardless of being pleasant or unpleasant, may provoke distinct physiological responses as opposed to stimuli of moderate arousal levels within the same valence categories (Sabatinelli et al., 2023). This observation beckons a more granular exploration, where isolating the most emotionally charged stimuli could reveal if such intensities modulate the interplay between ssVEP and LPP responses. Should the strength of their relationship amplify with the separation of high-arousal content, it would further support ssVEP and LPP measurements are indeed capturing similar emotional processing mechanisms. Future investigations could capitalize on these insights to develop a repository of empirically validated video clips, meticulously categorized to bolster the power of statistical analyses. Such a resource would not only refine the specificity of stimuli used in ERP research but also enhance the robustness of conclusions drawn about the shared or distinct emotional processes these physiological measures represent.

A second limitation that merits attention is the omission of accounting for perceived motion. While the current study meticulously ensured that the average pixel variation from one frame to the next was statistically consistent across different emotional categories, this method may not fully capture the essence of 'perceived action.' It is conceivable that the subjective perception of action may serve as a more accurate gauge for balancing the stimuli than a purely objective measure like pixel change. This subjective element could have intriguing implications for the relationship between ssVEP responses and self-reported arousal levels. For instance, it would be enlightening to investigate whether ssVEP responses are more profoundly modulated by the viewers' perception of action rather than the actual motion quantified by pixel change. Such an exploration could provide a deeper understanding of the interplay between the physiological impact of perceived dynamics in a scene and the objective measures of movement.

Another limitation arose due to the study's extended duration, approximately 120 minutes. To address logistical concerns, participants were advised that they did not need to view the entire 10-second video clip. Instead, they could determine the viewing length needed to provide responses on the SAM, even if merely a glance at the thumbnail sufficed. Such flexibility might have introduced discrepancies in the self-reported ratings. Notwithstanding the significant correlations on both by-scene and by-participant levels, the potential influence of third-party variables should not be overlooked. Future studies are encouraged to design paradigms that factor in participant fatigue to enhance the accuracy and reliability of the findings.

Additionally, the direct relationships between measures are purely associational and do not signify a causal relationship. Although both ssVEP and LPP are instrumental in mapping neural processes related to attention and emotional processing, respectively, a mere correlation between their amplitudes cannot be interpreted as one driving the other.

Future investigations should delve into the influence of low-level features on ssVEP responses to dynamic videos. The present study operated under the premise that elements contributing to an unrealistic emotional experience within the videos might influence ssVEP outcomes. However, the resilience of ssVEP responses to dynamic stimuli—specifically against factors like jump cuts, professional lighting, and the presence of actors—remains to be fully understood. Should ssVEP prove to be robust against these elements, it would pave the way for future research to more effectively determine the emotional salience of video stimuli.

Conclusions

This investigation delved into the nuances of emotional responses by employing varied physiological techniques, building upon prior research that emphasized modulated ssVEP responses to dynamic emotional stimuli like videos. Our findings echoed earlier studies, which noted that emotional static stimuli, such as pictures, significantly influenced the LPP and EPN, pointing to a comprehensive physiological sensitivity to diverse emotional mediums. One of the study's main emphasis was on the alignment of emotional processing mirrored in ERPs in response to static stimuli with the ssVEPs induced by dynamic stimuli. This exploration into the congruency between the neural mechanisms across varied emotional media formats produced notable results. Preliminary insights revealed a parallelism in cognitive processes gauged by both ssVEP and the LPP.

The observed emotional variances in EPN, LPP, and ssVEP amplitudes in relation to the emotional categories within the study provided further insights into our understanding of emotional processing. Particularly, the EPN exhibited heightened responsiveness to pleasant stimuli, while the LPP amplitude demonstrated pronounced reactions to both pleasant and unpleasant images in comparison to neutral ones. Furthermore, the modulation of the ssVEP resonated with previous works, showing decreased ssVEP responses for emotional visuals as opposed to neutral ones. This suggests a broader engagement of the brain's sensory and associative regions when processing emotionally rich content. Additionally, our study reinforced the consistent relationship between LPP amplitudes and self-reported arousal, emphasizing the brain's evolved capacity to detect emotional stimuli swiftly and accurately. The negative correlation observed between ssVEP amplitudes and self-reported measures, supported by prior studies, underscores the potential of ssVEPs as a temporally consistent physiological arousal marker. However, the significant correlation between ssVEP and LPP amplitudes found in our research diverges from earlier findings and calls for further exploration.

In summary, this study has explored a way for further understanding of emotional processing by juxtaposing static and dynamic stimuli's physiological responses. The results hold implications for the broader comprehension of how our brain processes emotions across different media formats. Future research endeavors should consider delving deeper into the correlation between ssVEP and LPP amplitudes, the influence of specific content on LPP reactivity, and further explorations into the physiological mechanisms underpinning emotional processing.

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