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Department of General Psychology
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Bachelor's Degree Course in Psychological Science

Final dissertation

Attention allocation under an emotional passive viewing paradigm: An steady-state visual evoked potential study

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To my Grandmother and Mother

Table of contents

Chapter 1: Introduction

1.1 Theories of attention

Prior to psychology's establishment as an empirical field of study in 1879, there was a strong focus on the topic of attention in the research of pioneering psychologists. Attention is related to many of the most well-known and extensively researched phenomena, and it was at the center of the "cognitive" revolution of the 1950s, which contributed to its current importance. Thereby, attention became admittedly, the core of cognitive psychology. As the American Psychological Association (APA) defines it, attention is *"[...] a state in which cognitive resources are focused on certain aspects of the environment rather than on others and the central nervous system is in a state of readiness to respond to stimuli."* (American Psychological Association, APA, 2022). Namely, research on attention examines how and why we choose to focus on certain elements of the flood of information present in both the internal and external environment. A consensus is reached about the subdivision of the overall domain of attention into at least four distinct areas—vigilance, arousal, divided attention, and selective attention (LaBerge, 1990). Focusing on the meta-analysis of (mainly) functional imaging studies, Corbetta & Shulman (2002) developed an influential model of attention by introducing two partially distinctive networks of brain areas carrying out different attentional functions. The first one is a cognitive, top-down (goal-directed) control system that is involved in preparing, applying, and controlling attention to stimuli in an endogenous manner. Organizing appropriate responses and detection of stimuli – particularly if pre-cued – are also its tasks. The second one, termed bottom-up (stimulus-driven) operates in an exogenous manner as a "circuit breaker" for the first system by identifying behaviorally relevant stimuli, particularly when salient or unexpected. Selective attention, as defined by APA (2022) is a *"[...] concentration on certain stimuli in the environment and not on others, enabling important stimuli to be distinguished from peripheral or incidental ones."* Selective attention is typically considered to be a voluntary, top-down process, however, some emotionally salient stimuli signaling threat or reward may receive precedence and be processed in a bottom-up (exogenous) manner.

1.2 Attention & Emotion

In the field of psychophysiology, a specific line of research has focused on the impact that emotional stimuli have on attentional processing and perception. For a stimulus to become of emotional importance, a value of valence is added; defined by the APA (2022) as: *"[...] the value associated with a stimulus as expressed on a continuum from pleasant to unpleasant or from attractive to aversive."* According to the evolutionary perspective, accurate reaction to unexpected or threatening stimuli is of beneficial importance to our survival. For an accurate reaction to take place, two primary functions are identified; the instant, involuntary capture of attention initiating further cognitive processing and the metabolic arousal of the organism, necessary for performing an accurate response to the situation (Bradley & Lang, 2010). As stated by Lang et al. (1997), motivation is the main factor that determines attention in the competitive realm of species survival, and it does so by the means of cortico-limbic appetitive and aversive (also termed defense) drive systems. The appetitive system activates in contexts that promote survival, whereas the defense system activates in contexts involving threats, each followed by an adequate behavioral response (Bradley, 2003). A judgment of pleasure is necessary for accurate system activation, while a judgment of arousal will index its intensity (Bradly & Lang, 2007). Inspecting such judgments is usually done by administering the Self-Assessment Manikin (SAM) questionnaire (Bradly & Lang, 1994). Since its development, SAM has been utilized in a large number of psychophysiological research due to its high validity and reliability. Consequently, for this cascade of events to take place, orienting one's attention to an affectively significant stimulus is of central importance (Bradley, 2009). For experimental investigations of emotion and attention, a database of emotional visual stimuli has been developed—providing a large set of normative, internationally accessible, color photographs including contents varying in semantic character— termed International Affective Picture System (IAPS) (Lang, Bradley & Cuthbert,1997). In experimental emotional research, it is one of the most trustworthy and widely used sources. (Jayaro, de la Vega, Díaz-Marsá, Montes, & Carrasco, 2008).

1.3 Electrophysiological discoveries

To have an insight into the temporal dynamics of attentional processing of emotional stimuli, researchers commonly use "event-related potentials" (ERPs), defined by the APA (2022) as *"[…] a specific pattern of electrical activity produced in the brain when a person is engaged in a cognitive act".* ERPs can be generated not only as a result of physical stimulation by a sensory stimulus (exogenous) but also by internal cognitive or motor processes (endogenous) (Norcia et al., (2015). There are numerous distinct ERP components, most of which have been associated with a particular cognitive process either by amplitude or latency. Many studies consistently report increased electrical brain activity in response to emotional compared to neutral visual scenes, making it a central hypothesis in the field (Olofsson, Nordin, Sequeira, & Polich, 2008). The most noticeable ones linked to the processing of emotional stimuli are N100, P100, N170, vertex positive potentials (VPP), N250, N300, P300, late positive potentials (LPP), and early posterior negativity (EPN), with LPP emerging consistently as a response to emotional stimuli, in the studies containing affective picture viewing design (Palomba, Angrilli & Bravi, 1996; Palomba, Angrilli & Mani, 1997; Olofsson, Nordin, Sequeira, & Polich, 2008; Hajcak, Dunning & Foti, 2009; Ding, Li, Wang, & Luo, 2017). The notion of motivated attention, which holds that emotion automatically directs attention and hence helps subsequent processing, has been used to explain why emotional compared to neutral stimuli are followed by larger parietal positivities. (Schettino, Gundlach & Müller, 2019). To investigate these effects, the Rapid Serial Visual Presentation (RSVP) paradigm is employed. Defined by APA (2022) as a: *"[...] methodology in which a series of visual stimuli, such as shapes or words, are presented in a very short time span, often just a few milliseconds per item*.". Images displayed at different presentation rates create clear masking effects and limit the availability of visual information to the presentation of each image. (Alonso-Prieto et al., 2013; Bekhtereva & Müller, 2015; Retter & Rossion, 2016). Hence, image processing is assessed using the Steady-state visual evoked potential (SSVEP); a continuous oscillatory brain response to a repetitive, flickering visual stimulus having the same temporal frequency as the driving stimulus (Müller et al., 2006). In contrast to the ERP research, the responses to such periodic stimuli can be very stable in amplitude and phase over time reflecting dynamic neural changes associated with the driving stimulus, making it an effective tool for monitoring the allocation of attentional resources toward stimuli over time and investigating temporal neural competitive dynamics or interactions. (Regan, 1966; Müller et al., 2006; Norcia et al.,2015). Importantly, research shows an increase in SSVEP amplitude during the RSVP stream of IAPS images for emotional compared to neutral images indicating the enhanced deployment of attention to emotional images (Keil et al.,2003; Bekhtereva et al., 2018). However, up to the present, it is still an open question whether these amplitude increases in response to emotional images are due to their semantics (i.e. erotic content) or whether these changes are driven by low-level features (such as more red color in mutilation scenes). The present study set out by investigating that question. To this end, we presented concrete and scrambled IAPS images (see Methods) with pleasant, unpleasant, and neutral content. We hypothesize that an increase in amplitude would be due to the semantics in comparison to low-level features of images. Furthermore, we expect an increase in the amplitude in response to the emotional compared to neutral stimuli for concrete, but not for scrambled images.

Chapter 2: Methods

2.1 Participants

The sample was composed of 16 participants, mostly university students (11 women, mean age: 24.27 ± 3.44 years; 5 men, mean age: 22.8 ± 0.74 years) with normal or corrected-to-normal vision. Three left-handed and 13 right-handed individuals were recruited. The experiment was advertised at the University of Leipzig and participants received a monetary contribution. In line with the Declaration of Helsinki, all participants gave their written informed consent to take part in the experiment and were 18 years or older. The experimental procedure was approved by the Psychology Ethics Committee of the University of Leipzig.

2.2 Stimuli

Stimuli utilized in the experiment consisted of concrete and scrambled images, each sub-divided into three levels: neutral, pleasant, and unpleasant respectively (Figure 1). A total of 420 scenes were used, with 210 used for each category of images and 70 for each condition. Images were pre-processed with MATLAB image processing toolbox together with SHINE image toolbox to assess equal mean luminance and mean RMS contrast between the experimental image categories. Every image used in the study was taken from the International Affective Picture System (IAPS) (Lang, Bradley & Cuthbert, 1997). Concrete images were the original images taken from the database—without any distortion across all levels— depicting either emotionally pleasant (e.g., erotic, couples, babies), unpleasant (e.g., mutilation, attack scenes, threat) or neutral contents (e.g., household objects, neutral faces).

However, scrambled images were produced by applying a Fourier transform in a three-step process: (i) For each image, the amplitude and phase components were collected, (ii) Each image's original phase spectrum was replaced with randomized phase components while the original amplitude spectrum was kept, (iii) Rebuilding each new scrambled image using an inverse Fourier transform. Images produced by this image-scrambling process had the same low-level physical characteristics as their originals (e.g., spatial frequency content, color, contrast), while any content-related information was distorted. Namely, all images were presented centrally against a black background on a PROPixx by VPixx Technologies projector with a resolution of 1920 x 1080, and frame refresh rate up to 1440 Hz at a viewing distance of 80 cm from the monitor, producing a stimulus presentation of 10.36° x 8.22 ° visual angle.

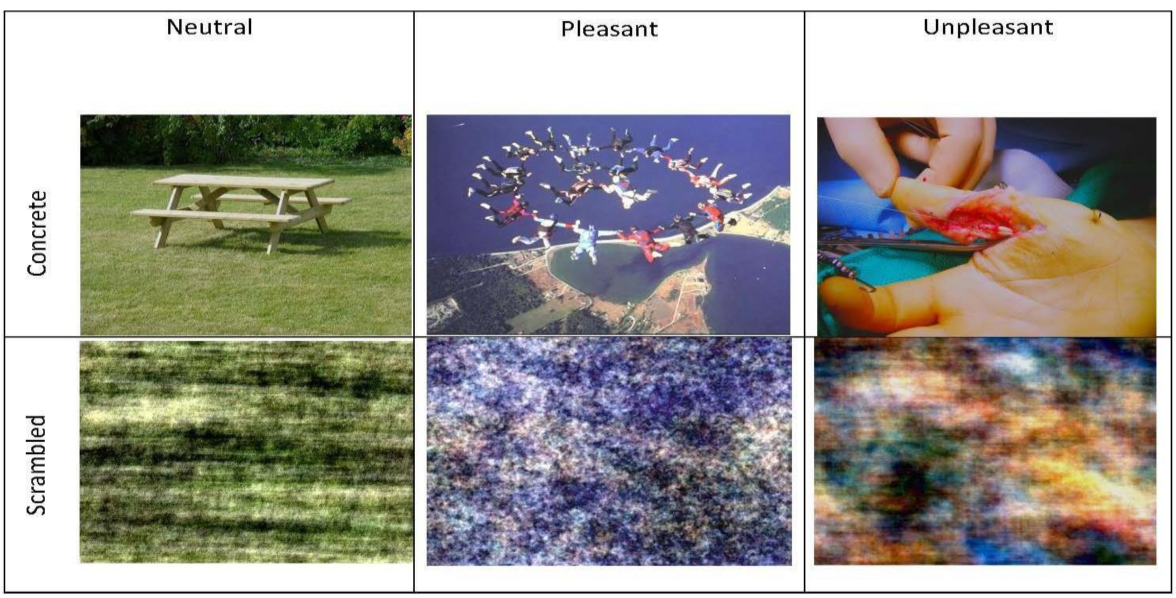

Figure 1: Concrete images across conditions (upper row) and their scrambled equivalents (bottom row)

2.3 RSVP streams

In the experimental condition, images were displayed within a Rapid Serial Visual Presentation (RSVP) paradigm. One RSVP stream per condition was employed, resulting in a neutral, pleasant, and unpleasant stream, each containing concrete images or their scrambled equivalents of respected conditions. There were 360 trials in total, with 120 trials per condition. To avoid anticipation effects for the time point of the change to a concrete image, a time variance of four, six, or eight seconds per trial was set for each of the 120 trials within a stream. Randomization of images within trials was distributed, with each image being presented for 250 milliseconds at a frequency of 4 Hz.

2.4 Procedure

After the participants were introduced to the experimental procedure and signed Informed Consent, a training part was performed consisting of ten trials. The training part enabled participants to familiarize themselves with the procedure and experimental design. Consequently, participants were asked to take a comfortable seat, while the EEG montage was performed. EEG data were collected during the passive viewing task using 64 Ag/AgCl scalp electrodes (Biosemi, Amsterdam), according to the 10-20 International System. Six additional bipolar channels were assembled, recording vertical and horizontal eye movements with standard HEOG and VEOG montages as well as cardiac response (ECG). During the collection of EEG signals, ocular fixation was controlled by instructing each subject to keep fixation on the central cross and passively view an RSVP stream of images. Upon the end of the passive viewing task, EEG was disassembled and participants were asked to subjectively assess their affection by rating both pleasantness and arousal via a computerized Self-Assessment Manikin (SAM) questionnaire set up with the Matlab

Toolbox (Bradley & Lang, 1994). Both the valence (unpleasant-pleasant) and arousal (calm-excited) judgment scales ranged from 1 (low) to 9 (high). (Figure 2)

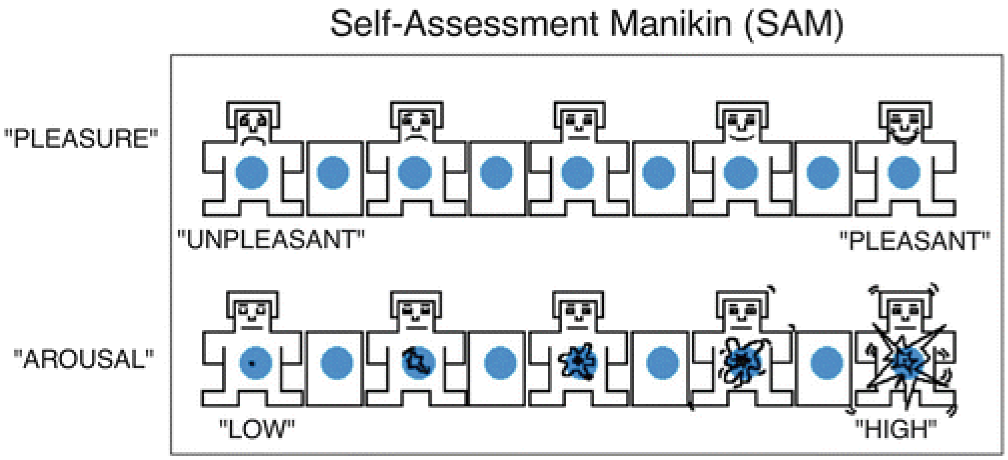

Figure 2: Example of a self-report SAM rating scale. From: "International Affective Picture System", By M.M. Bradley, P.J. Lang, 2017, April 13, *Encyclopedia of Personality and Individual Differences.* Springer, Cham. https://doi.org/10.1007/978-3-319-28099-8_42-1

2.5 EEG preprocessing and analysis

Throughout the recording, the impedance was kept below 5 kΩ and the sampling rate was set at 512 Hz with a low-pass filter of 104 Hz and stored for later offline analysis. Before the statistical analysis, data were analyzed offline within the Brainstorm toolbox of Matlab. EEG analysis followed the procedure described by Keil et al., 2003. In short: Individual epochs were extracted between -3000 milliseconds (ms) before and 3000 ms after the onset of a concrete image. These epochs were inspected for eye movements, blinks, and noise in the recorded channels, such as muscle artifacts, and subsequently removed for further analysis. Consequently, Independent component analysis (ICA), a computational method for decomposing a signal into its constituent parts, was carried out. ICA enables verification that no noise is present in the recording. For statistical analysis in the present thesis, only Oz electrode was used. In such a design with centrally presented stimuli, Oz exhibits the greatest amplitudes. Two time windows — from -1.500 to -500, i.e. when scrambled images were presented, and 500 to 1.500, with concrete images — of artifact-free epochs of electrode Oz were transformed into the frequency domain by means of a standard Fast Fourier Transform (FFT). The respective amplitude values at 4 Hz were taken for statistical analysis.

2.6 Statistical analysis

The statistical analysis was carried out in the program RStudio using ANOVA and paired T-statistic methods. Assessing whether images used in the study are conveying the intended semantic meaning was done utilizing paired T-statistic on conditions within both valence and arousal categories of the self-report questionnaire Self-Assessment Manikin (SAM). Once images' perceived emotional valence and intensity of arousal were established, we started analyzing SSVEP amplitude data. Analysis of variance (ANOVA) defined by APA as: *"[…] a statistical method of studying the variation in responses of two or more groups on a dependent variable."* Was used to assess the differences in variance between conditions (neutral, pleasant, and unpleasant) within both scrambled and concrete image categories. Consequently, post hoc T-statistics provided us with a thorough insight into the mean differences between the conditions within a category of concrete images.

2.7 SAM questionnaire analysis

The T-statistic on valence and arousal was conducted to inspect whether the images taken from the International Affective Picture System (IAPS) are suitable. As expected, the valence was perceived as significantly lower for images belonging to the neutral (M = 4.88, SD = 0.48) compared to the pleasant (M = 7.45, SD = 0.67) category of concrete images ($t_{15} = -13.53$, $p < .001$). However, participants scored unpleasant images (M = 2.62, SD = 0.61) as much less valent than neutral images (M = 4.88, SD = 0.48), ($t_{15} = 11.93$, $p < .001$), in line with our expectations. Coherently, viewing pleasant images (M = 7.45, SD = 0.67) was perceived as more valent in comparison to unpleasant images (M = 2.62, SD = 0.61), ($t_{15} = 24.71$, $p < .001$). Analysis of the arousal scale provided significant differences between neutral (M = 3.93, SD = 0.91) compared to both pleasant (M = 7.07, SD = 0.66) and unpleasant (M = 7.45, SD = 0.64) concrete images, with emotional visual stimuli rated higher in arousal ($t_{15} = -10.94$, $p < .001$) ($t_{15} = -14.40$, $p < .001$). In opposition to valence analysis, and in line with our hypothesis, emotional visual stimuli conveying opposite semantic content showed no difference in arousal with both pleasant and unpleasant images rated as highly arousing ($t_{15} = -1.50$, $p < 0.07$).

2.8 SSVEP analysis

The T-statistic was performed to compare amplitude enhancement between the same categories of stimuli belonging to either scrambled or concrete group of images. Significant differences were revealed for scrambled vs. concrete images across all conditions, as reported in Figure 3 in microvolts. Respectively, differences were found between neutral concrete images (M = 5.92, SD = 2.87) and their scrambled equivalents (M = 1.83, SD = 1.86) ($t_{15} = -6.95$, $p < .001$), as well as for pleasant concrete (M = 9.21, SD = 3.69) vs. pleasant scrambled (M = 1.95, SD = 2.11) ($t_{15} = -9.33$, $p < .001$), and unpleasant concrete (M = 8.53, SD = 3.85) vs. unpleasant scrambled (M = 1.79, SD = 2.19) ($t_{15} = -8.04$, $p < .001$) with higher amplitudes in all the categories of stimuli belonging to the concrete group of images.

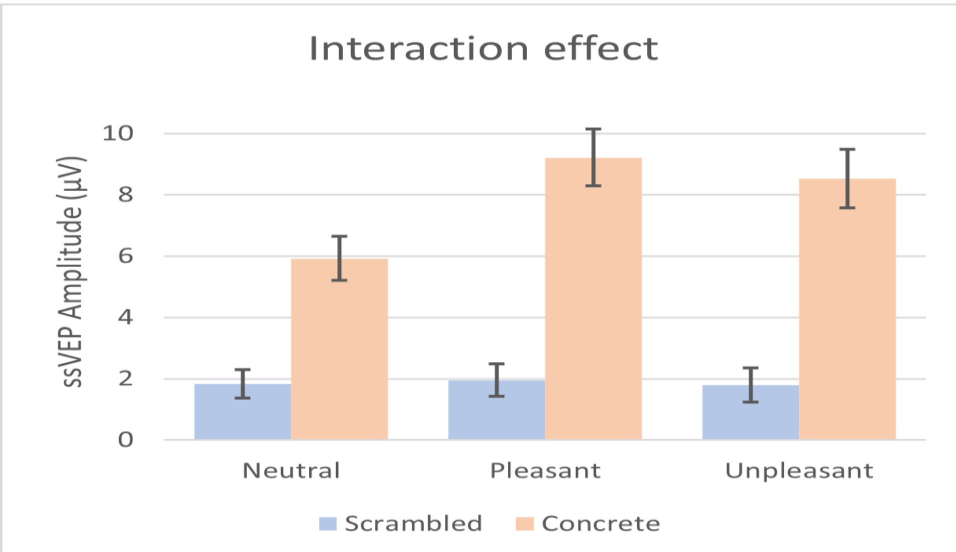

Figure 3: Categories of stimuli x types of images

2.8.1 Scrambled images

As hypothesized, the analysis of variance (ANOVA) carried out on the scrambled group and its three sub-levels showed no significant differences in the SSVEP amplitude across all categories of scrambled images ($F_{2,45} = 0.02$, $p < 0.9$).

2.8.2 Concrete images

Data analysis performed on the group of concrete images taken from the IAPS database found significant differences between means of different categories of stimuli ($F_{2,45} = 3.93$, $p < 0.02$). To assess differences in the amplitude between categories of stimuli within a group of concrete images, a post hoc t-statistic was conducted. Significant differences were found between neutral vs. emotional stimuli, but not between the two categories of emotional stimuli. Prominently higher amplitude was found in pleasant (M = 9.21, SD =3.69) vs. neutral (M = 5.92, SD = 2.87) categories of stimuli ($t_{15} = -8.83$, $p < .001$) as well as in unpleasant (M = 8.53, SD =3.85) vs. neutral (M = 5.92, SD = 2.87), ($t_{15} = -7.04$, $p < .001$). There were no differences in the amplitude between pleasant (M = 9.21, SD = 3.69) vs unpleasant images (M = 8.53, SD = 3.85) ($t_{15} = 1.63$, $p < 0.06$).

Chapter 3: Discussion and final remarks

This research aimed to investigate the electrophysiological responses to various visual stimuli to determine whether the semantic content or low-level features of images has a main effect in directing and facilitating the allocation of attention. In line with previous findings such as the one of Bradley et al., (2009), it was also hypothesized that emotional stimuli would modulate amplitude enhancement for concrete images due to the activation of fundamental motivational systems that have evolved to support survival. Namely, contrasting patterns in SSVEP amplitude can be noted in response to concrete compared to scrambled images under a passive viewing task. Presenting a new image every 250 ms (i.e., 4 Hz) in RSVP streams of distinct conditions (neutral, pleasant, and unpleasant) resulted in consistent SSVEP amplitude increase for all conditions belonging to the concrete images' category in comparison to their scrambled equivalents. Scrambled images consistently showed no significant electrophysiological activation of the visual system across all three sub-levels indicating that low-level features of images cannot be seen as the main factor in attention capturing. A further critical finding was that a significant amplitude enhancement was found in response to concrete images of emotional character, hence, the most affectively arousing images generally prompted more extensive and sustained electrophysiological activation than other image contents. Therefore, the two image conditions that most intensely activate the primary motivational systems—pleasant (erotica, happy families) and unpleasant (mutilation, and threat)— all elicited noticeably higher activation compared to neutral and less affectively arousing images. Critically, differences in the affective SSVEP modulations for emotionally arousing images could not rely strongly on the low-level features of images, such as spatial frequency content, color, and contrast. The current experiment demonstrates unequivocally that color—such as red in some images depicting mutilation or erotic content—is not a significant variable. The results obtained are supported by the literature and in line with similar studies such as the work of Bradley et al. (2003) where the same pattern of functional activation was found regardless of the color of the images presented. Furthermore, results suggest that even a very quick shift in emotional valence within continuous RSVP streams of neutral or emotional (affectively charged) visual stimuli strongly modulates the visual cortex. In the future, more research could be done where physiological indices such as skin conductance and heart are taken into consideration, besides just the ERPs, to gain a better insight into attention-capturing mechanisms. A more pronounced activation of the visual system in response to highly arousing stimuli can be interpreted in terms of "motivated attention," where defensive or appetitive motivational engagement directs attention and facilitates the processing of stimuli that are important for survival from an evolutionary perspective. Considering that many studies in the field have been done under a passive viewing paradigm, more experiments could be made using a foreground task to further examine the allocation of attention under distraction.

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Figure 2:

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