ABSTRACT

LEE, JA YOUNG. The Effects of Individual Difference on Discrete Affective Stimuli Processing: An EEG Study. (Under the direction of Dr. Chang S. Nam.)

Engineering has been considered to be in the realm of rationality. In recent days, however, people started to think about the role of emotion in engineering, as they realize that emotion motivates our actions and decision-makings. According to the literature, emotions regulate various human behaviors (e.g., purchasing, risk-management, health-related habit, socializing) and it influences the engineering outcome of systems (e.g., trust, accuracy, efficiency, safety, satisfaction, etc.).

Bearing such significance of emotions in mind, the present study investigated how people process discrete affective picture stimuli, using electroencephalogram (EEG). Pictures in five different emotional categories (awe, excite, fear, disgust, and neutral) were presented to twenty male participants, and brain signals were measured during the image presentation. Furthermore, in order to examine how the emotion perception is affected by individual's emotional intelligence (granularity), the tendency to represent emotional experience with precision and specificity, each participant's emotional granularity was measured through an online survey. Event-related potential (ERP) and coherence of brain areas were then analyzed, subject to emotional granularity and discrete emotional categories.

The results showed that: (a) each discrete emotion exhibits different pattern of brain activation after about 170ms, (b) highly granular people display more activation of brain cortex in the early stage (before 300ms), but smaller and delayed activation in the later stage (after 300ms), and (c) high granular people experience less emotional regulation, represented by coherence between prefrontal and parietal area in beta frequency band (13-30Hz).

Overall results suggested the importance of studying discrete emotions, rather than general affective state, in order to get a better picture of affective neural process. In addition, individual difference in emotional granularity was in harness with domain-general cognitive functions such as selective attention and less regulation in emotional experience. Taken together, the present study demonstrated that understanding human emotions would give insights beyond traditional knowledge and experiences.

The Effects of Individual Difference on Discrete Affective Stimuli Processing: An EEG Study

by
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BIOGRAPHY

Ja Young Lee was born in Busan, South Korea in 1990, and raised in Bundang, a major city in the Seoul Capital Area. She spent a year of her adolescence in Phoenix, Arizona and learned how to embrace people from all walks of life. After she returned to Korea, she received her B.S. in Industrial Engineering from Seoul National University, and decided to pursue M.S. degree in United States, where she can challenge herself. Currently she is pursuing her degree in the Human Factors and Ergonomics Area in the Department of Industrial and Systems Engineering at North Carolina State University, under the guidance of Dr. Chang S. Nam. Her research interest is broad in human-computer interaction and her research goal is to help people using technology more efficiently.

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations	**Intended Meaning**
BA	Brodmann’s Area
BAI	Beck Anxiety Inventory
BCI	Brain-Computer Interface
BDI	Beck Depression Inventory
CAR	Common Average Reference
DRM	Day Reconstruction Method
EEG	Electroencephalography
EPN	Early Posterior Negativity
ERD/ERS	Event-Related Desynchronization/Synchronization
ERP	Event-Related Potential
fMRI	Functional Magnetic Resonance Imaging
IAPS	International Affective Picture System
ICC	Intra-class Correlation
LPP	Late Positive Potential
PET	Positron Emission Tomography
SAM	Self-Assessment Manikin

Abbreviations are in an alphabetical order.

1. INTRODUCTION

1.1. Context and Motivation

For many hundreds of years, emotions were regarded as an opposition of a more lofty and desirable process of reason. Even in 1950s, B.F. Skinner's behaviorism argued, "the 'emotions' are excellent examples of the fictional causes to which we commonly attribute behavior" (p.160, Skinner, 1953). The dominant view had been that emotions were not functional, vital, or necessary. However, other researchers since 1920s started to think differently – emotions are fundamental to human social behavior, and cultivating positive emotions might be critical for optimal physical and psychological functioning – and the study of emotion became active.

In assessing the emotional state, the primary means have been subjective self-reports (e.g., Self-Assessment Manikin by Bradley & Lang, 1994) or observing facial expressions (Ekman, 1993). However, it is hard to objectively measure the experience of emotion with these measures and representations of emotion do not always converge into a unitary emotion (Barrett, 2006; Mauss & Robinson, 2009). So understanding the neural basis of emotion was proposed, as it can provide better insight to the nature of human emotions (see Panksepp, 1998). Measuring neural activity could be measured by functional magnetic resonance imaging (fMRI), positron emission tomography (PET), or electroencephalography (EEG). Among these methods, EEG has been widely used for emotion study. It measures immediate cortical responses of brain with high temporal resolution, by capturing the current flow produced by synaptic excitation of neurons in the cerebral cortex (Teplan, 2002). Although it cannot precisely localize the sites of activation like PET and fMRI, it can help defining the time course of activation.

The scientific community still has a vague picture on the emotional process, and there are ongoing debates about the definitions, conceptual models, and neural process of human emotions. From affective EEG study's perspective, in specific, most of the previous studies did not fully appreciate possible source of variations. First, the focus of emotion EEG studies has been mostly on general affective states (pleasant and unpleasant) instead of discrete emotions (e.g., awe, excite, fear, disgust), failing to interpret electrical brain correlates of different discrete emotions (Hot & Sequeira, 2013; Krusemark & Li, 2011). Difficulty of covering all types of emotional events with discrete emotional categories encouraged researchers to classify emotions on simple dimensions, and to make stimulus database based on such simple dimension (e.g., valence and arousal). Easy access to such database caused large quantity of emotion studies to focus on the effect of valence or arousal, rather than that of discrete emotions. Second, individual differences in emotional intelligence were not widely considered, although it can contribute to the emotional processing to a great extent (Lindquist & Barrett, 2008). The present study supposes that studying discrete emotions and harnessing individual difference will help identifying the neural representation of emotional processes and will give light on the understanding of human emotions. From the cognitive engineering perspective, this study would extend the classical skill-, rule-, or knowledge-based cognitive engineering framework to emotion-based performance models, and help understand personal attributes that exercise important control on human performance (Gielo-Perczak & Karwowski, 2003; Rasmussen, 1983).

1.2. Purpose of Study

1.2.1. Research Questions

Previous studies gave rise to several questions about neural process of emotion. First, do different emotional contents undergo different neural process? Which emotion model (constructionist vs. locationist) better explains affective process? Second, what causes individual difference in emotional intelligence? What does it imply in terms of emotional process? The present study aimed to address these questions.

1.2.2. Significance of the Study

Collectively from previous literatures, human emotions are a subset of affective phenomena initiated by evaluating the personal meaning of some prior events. It influences consequent thoughts, decisions, and behaviors as well as bodily responses such as muscle activity, heart rate, or skin conductance. In specific, emotion affects our memory (Bechara, 2004; Kahneman, 2003), health (Kring & Moran, 2008; Kubzansky & Kawachi, 2000; Pressman & Cohen, 2005), cooperation (Mackie, Devos, & Smith, 2000), and social behavior (Clore, Schwarz, & Conway, 1994; Gottman, Katz, & Hooven, 1996; Morris & Keltner, 2000). Emotion also physically prepares one to make rapid responses (Frijda, 1986); negative emotion activates autonomic nervous system to be ready for actions (Tugade, Fredrickson, & Feldman Barrett, 2004).

The functions of emotion influence human performance in wide range of fields, such as management (Ashforth & Humphrey, 1995; Cavicchio & Poesio, 2012), education (Isen & Means, 1983; Schutz & Pekrun, 2007), healthcare (Harrison, Sullivan, Tchanturia, & Treasure, 2010; Raghunathan & Trope, 2002), interface design (Brave & Nass, 2003; Kim & Moon, 1998; Merritt, 2011; Pelet, Conway, Papadopoulou, & Limayem, 2013), product design (Chien & Lin, 2014; Horn & Salvendy, 2006; Horn & Salvendy, 2009; Norman, 2004), and safety (Causse, Dehais, Péran, Sabatini, & Pastor, 2013; Zhang & Kaber, 2013). Thus, studying neural basis of emotion will add value to the neuroergonomics area and help designing more efficient and safe system, based on the understanding of the relationship between brain function and human performance.

1.3. Thesis Outline

This thesis is organized as follows. Section 1 briefly presented the background and aim of the study. Section 2 reviewed previous studies related to the study. In this section, first, ongoing debates about emotion models and emotion classes were introduced. Second, a concept of emotional intelligence (granularity) was introduced in favor of constructionist approach. Third, two EEG methods (ERP and coherence) and the meanings of their components were described in detail. Lastly, hypotheses of the present study were listed. Section 3 explained methodology for this study, and Section 4 showed the results of the experiment. Section 5 stated the meanings, limitations, and implications of this study.

2. LITERATURE REVIEW

2.1. What is Emotion?

It has been hard for researchers to arrive at a consensual definition of emotion. In recent days, emotion was defined as “episodic, relatively short-term, biologically-based patterns of perception, experience, physiology, action, and communication that occur in response to specific physical and social challenges and opportunities” (Keltner & Gross, 1999, p.468), or similarly as “transient, bio-psychosocial reactions designed to aid individuals in adapting to and coping with events that have implications for survival and well-being” (Sander & Scherer, 2009, p.69). These definitions commonly emphasize that emotion is (a) a transitory condition with (b) biological and perceptual reactions (c) in order to manage a given situation. Emotion should not be confused with ‘mood’ or ‘temperament’, as mood or temperament is not a specific response to anything, but rather a long-lasting state. It is normally induced by sustained exposure to affective stimuli and lasts for longer time periods (Bradley & Lang, 2000). Table 1 summarizes the difference between emotion and mood. On the other hand, ‘affect’ is “a general term that has come to mean anything emotional”, in the science of emotion (Barrett & Bliss-Moreau, 2009).

Table 1 Comparison of ‘emotion’ and ‘mood’

	Emotion	Mood
Duration	Short, lasting seconds unless stimulus persists	Long, lasting minutes to days
Responsiveness	Fluctuating, reactive	Stable, diffuse
Object	Focused on a particular event	Unfocused
Function	To focus attention, to provide information to the organism	To instigate, facilitate, sustain and modify active engagement with the environment

(Revised from Table 2.1 of Gray, Watson, Payne, & Cooper, 2001 and Figure 5.3 of Lottridge, Chignell, & Jovicic, 2011)

There have been various emotion theories and concepts that explain the whole range of emotions comprehensively. In a broad sense, two different frameworks for emotion model will be discussed in the following sections: the first is constructionist vs. basic vs. appraisal theory debate on the cognitive system of emotion, and the second is neural model debate between functionalists and constructionists.

2.1.1. Constructionist Theories vs. Basic Emotion Theories vs. Appraisal Theories

According to the early constructivist (constructionist) theory by Schachter and Singer (1962), an emotional state is based on two factors: 'cognition of arousing situation' and 'perceived physiological arousal' produced by stimuli. People evaluate the situational context and infer appropriate emotion to feel based on these arousals (Mandler, 1990). More recent constructivist theory (Barrett, 2006) stated that 'core affect' and 'conceptualization' shape mental states. A basic rule is that core affect, caused by a large number of different factors, is made meaningful through categorization (conceptualization) and develops into an emotional feeling. In this model, the connection between core affect and conceptualization is based on situational factors and socio-cultural factors stored in memory.

Ekman's basic emotion model (Ekman & Friesen, 2003; Izard, 1991), on the other hand, argues that emotions categories are separate entities, given by the structure of the neuronal system. According to the model, a certain type of event is automatically appraised via database lookup and one of basic emotions is determined. Thus, it is relatively deterministic in a macro level.

Appraisal theories (e.g., Ellsworth & Scherer, 2003; Smith & Ellsworth, 1985) are deterministic in more micro-level. The basic premise of appraisal theory is that emotions are elicited by the subjective interpretation of events, based on appraisal dimensions (e.g., novelty, coping potential, importance, etc.). The theorists claim that specific interpretations and explanations of event causally determine emotion (even without 'arousals' mentioned by Schachter and Singer), and the emergent emotion is formed by recursive process of the appraisal. It seems like the appraisal model is slightly embedded in the constructionist model in the process of producing core affect, because the constructionist process includes appraising somatosensory feedbacks as well as situational meaning. However, constructionists do not accept the micro-level deterministic process of the appraisal model. Table 2 compares aforementioned theories.

Table 2 Comparison of emotion theories

	Constructionist theories	Basic emotion theories	Appraisal theories
Theorists	Stanley Schechter (early two-factor theory of emotion), James Russell, Lisa Feldman Barrett	Paul Ekman, Carroll Izard (differential emotions theory)	Klaus Scherer, Nico Frijda, Ira Roseman, Phoebe Ellsworth, Craig Smith
Premise	Emotions are biologically and socially constructed complex syndromes	There are biologically determined core emotions	Determining emotion is through stimulus evaluation based on appraisal dimensions
Connection to affective neuroscience	Constructionist models	Locationist models	Typically do not integrate neuroscientific concepts and findings

2.1.2. Locationist Models vs. Constructionist Models

From a neural perspective, MacLean (1990) suggested that our 'triune brain' conceptually consists of three neural parts that supervise emotional process: the reptilian core (the innate behaviors related to instinctive reaction to survival issues), the old mammalian brain (the affective reactions that control subjective feelings and motivational system), and the neomammalian cortex (the declarative knowledge that generates logical thoughts and reasoning). More recently, particular brain sites, such as hypothalamus, cingulate cortex, orbitofrontal cortex, thalamus, amygdala, hippocampus, medulla, occipital cortex, and so forth, are known to participate in emotion, thanks to the neuroimaging technologies (Kober et al., 2008; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Vytal & Hamann, 2010). However, it is still dubious through which path an individual emotion is processed in human brain.

There are roughly two different views on this matter. It was suggested that emotions are processed by either specialized and separate centers or motor and sensory centers that are already assigned to specific functions. The former shape the locationist account and the latter forms constructionist account. Many of the recent emotion research made locationist assumptions and tried to distinguish different cortical and subcortical activity signature for each emotion (Lindquist et al., 2012). The hypothesis is that people have internal mechanisms for discrete emotion entities, and there is individual neural structure (e.g., Baumann & Mattingley, 2012; Calder, Keane, Manes, Antoun, & Young, 2000; Pessoa & Adolphs, 2010) or neural networks specialized for each emotion (e.g., Panksepp, 2011; Pessoa, 2012; Phillips et al., 1997) like Ekman's basic emotion model. However, a great deal of studies failed to find consistence evidence for distinct anatomical patterns that distinguishes emotional categories (Lindquist et al., 2012; e.g., Mauss & Robinson, 2009; Vytal & Hamann, 2010).

The idea of neural reuse (Anderson, 2010) leads to the constructionist hypothesis. Constructionist approach to the mind considers emotion as a more generic type of mental function. Just like some basic psychological processes are common in diverse tasks (Cole & Schneider, 2007; Dosenbach et al., 2006; Van Snellenberg & Wager, 2009; Wager & Smith, 2003), from the constructionist point of view, emotion categories might also share large-scale networks intrinsic to brain. From the constructionist view, emotions consist of psychological building blocks that form basic functions: representing the state of the body, using knowledge to make meaning of sensations, and processing external sensations. Similar approaches have existed since the beginning of psychology, and it became increasingly significant as a framework of connecting mind to brain (Barrett & Bliss-Moreau, 2009; Lindquist & Barrett, 2012). In often cases, a certain brain site is observed to be activated for a specific emotion. For instance, many studies reported fear-amygdala correspondence. However, according to the constructionist model, it may be because of different features such as novelty or uncertainty of stimuli. Amygdala may be simply in charge of predicting the uncertainty of a stimulus (Barrett, 2006).

The constructionist model is connected to the constructionist theory mentioned in the previous section. According to the model, emotional experiences occur when person conceptualizes an instance of affective feeling, based on their conceptual knowledge (Barrett, 2006). The process can be decomposed into small brain networks that generate and represent core affect, categorize based on situation and experience, and support executive attention to retrieve concepts (Kober et al., 2008; Lindquist et al., 2012; Oosterwijk et al., 2012; Wilson-Mendenhall, Barrett, & Barsalou, 2013). Activation of these networks changes in real time as individual's body feelings or situation changes.

Core affect is a basic unit of emotion (Barrett & Bliss-Moreau, 2009; Russell & Barrett, 1999; Russell, 2003). Sensory inputs, such as raw somatic, visceral, vascular, and motor cues arousal interact together and the brain makes and initial top-down prediction about the meaning of the inputs (Bar, 2003). To produce a unified concept, errors between bottom-up information from core affect and top-down prediction is minimized (Friston, 2010). It is done by modifying prediction to fit to the situation or behavioral plan (Barrett, 2006) and to the stored representations of prior experiences, such as memories or language (Wilson-Mendenhall et al., 2013). Words take part in conceptualization when perceivers make meaning out of core affects, as language plays an important role in integrating different states into one category (Gentner & Goldin-Meadow, 2003).

Executive attention realizes the emotional gestalts into emotional representations (Barrett, Tugade, & Engle, 2004; Kanske & Kotz, 2011). Each represented emotion can be measured as a distinctive pattern of casual indicators, such as behavior, facial muscles, subjective feeling, or vocal acoustics. Figure 1 summarizes the constructionist process of emotion.

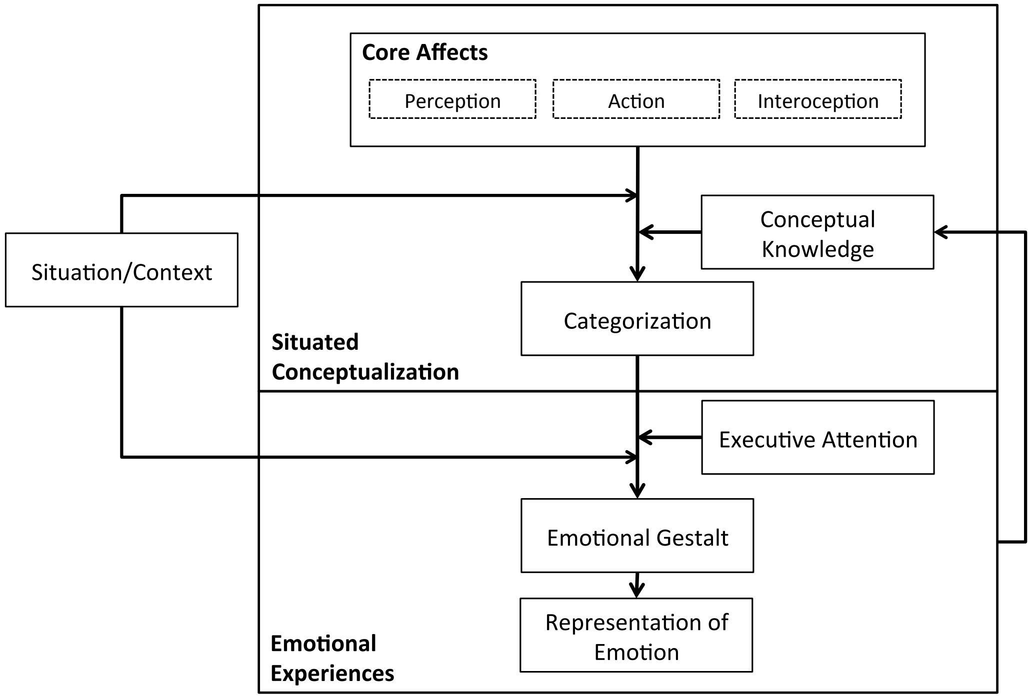


Figure 1 A simplified diagram of constructionist model

2.1.3. Implications for the Present Study

Emotion studies have explicitly or implicitly supported one of these affective processing models. Studies about facial expressions commonly added evidence to the basic, appraisal, and locationist models (e.g., Izard, Huebner, Risser, & Dougherty, 1980; Tracy & Robins, 2004; Young et al., 1997). On the contrary, many literatures observed that there is no distinct neural signature for discrete emotions. Emotional process might not be a separate function for emotion, but a part of general mental process. This study favors the latter constructionist view that admits innate variability of emotion as a general mental process and emotions' potential connection with other brain functions. By doing this, we will be able to see if human emotions are directly connected to human performance in neural level.

2.2. Emotion Categories

2.2.1. Classification of Emotions

Basic emotions proposed by Ekman include anger, disgust, fear, enjoyment, sadness and surprise (Ekman & Friesen, 2003). However, because it is difficult to encompass all other possible types of affective phenomena, such as joy, pride, amazement, tenderness, frustration, anguish, despair, shame, or panic, researchers have used various criteria to classify emotions in previous studies. Circumplex models place discrete emotions on the circle, based on their similarity or relatedness. The two perpendicular dimensions in a circle varied by model: Russell (1980) used arousal-valence dimension, Watson & Tellegen (1985) used engage-valence dimension, and Thayer (1989) used tension-energy dimension. Shaver et al. (1987), on the other hand, classified emotional words using a hierarchical cluster analysis. There also have been many trials to assign discrete emotion in a certain dimensional space such as SAM (Self-Assessment Manikin), PAD (Pleasure-Arousal-Dominance by Mehrabian, 1996), and PANAS-X (Positive Affect Negative Affect Scale by Watson & Clark, 1999). These are not mutually exclusive, but developed based on each other.

2.2.2. Stimulus for Experiments

Stimuli for the experiments had been mostly visual or auditory. It was known that detecting and interpreting of affect in the human voices is a complex issue (Banse & Scherer, 1996; Zinken, Knoll, & Panksepp, 2008) and affective information is communicated via nonlinguistic parts (Scherer & Wallbott, 1994), most studies have used emotionally affective images. Short presentation of picture stimulus could produce emotion, with non-affective components (noise) minimized.

Several standardized emotional stimuli (e.g., films, pictures, sound, odor) were used to elicit a certain emotion or emotion dimension. International Affective Picture System (IAPS by Lang, Bradley, & Cuthbert, 1999) use two-dimensional affective space with valence (positive and negative) axis and arousal axis. This system has normative ratings of the valence and arousal associated with each picture, obtained from SAM. It has supported many studies by providing standard emotional stimuli.

Behavioral Activation System (BAS) and Behavioral Inhibition System (BIS) scales (Beck, Smits, Claes, Vandereycken, & Bijttebier, 2009; Bijttebier, Beck, Claes, & Vandereycken, 2009) classify emotions into two motive systems: aversive that result in withdrawal behaviors, and appetitive that lead to approach behaviors. It is similar to the preservative vs. protective system (Konorski, 1967) or attractive vs. aversive system (Dickinson & Dearing, 1979). For example, fear and sadness were differed from anger (same valence, but anger expresses approach motivation) in terms of brain responses (Hoekert, Bais, Kahn, & Aleman, 2008; Van Rijn et al., 2005). This indicates that underlying activation of neural circuits could show different patterns, even though two emotions are similar in arousal and valence dimensions.

2.2.3. Implications for the Present Study

Standardized stimulus set allows standardized emotion testing. It can help identifying the effect of different tasks, personality, environment, and so forth. However, there is a lack of such database for discrete emotions. Mikels' norm (2005) is the one that identifies IAPS images that elicit one discrete emotion more than others. Discrete emotional terms used in this database were: amusement, awe, contentment, excitement, anger, disgust, fear, and sadness. Some were undifferentiated, and some image evoked emotion that overlapped between more than two emotions. The present study focused on such discrete emotions to reveal variances in emotional processes of between emotions, as they can possibly affect a certain type of human performance differently, such as risk-related behaviors (Cavicchio & Poesio, 2012), or coping with workload, stress, and exhaustion (Lee & Lee, 2001). It can also guide the discrete affective design of various interfaces. The use of discrete emotion database will help studying such effects.

2.3. Individual Differences in Affective Processing

2.3.1. Determinants of Affective Processing

There are individual differences that impact brain reactivity to emotional inputs (Canli, 2006; Hamann & Canli, 2004). Physical traits of people such as handedness, gender, age, genetic factors, or hormonal influences are the main sources (see Toga & Thompson, 2003), and personality traits such as neuroticism, extraversion-introversion, or mood state are other sources (Gale, Edwards, Morris, Moore, & Forrester, 2001; Lim, Woo, Bahn, & Nam, 2012). Table 3 shows how these factors influence brain activity. A limitation of these personalities, however, is that they cannot directly influence emotional process. For example, sad mood disturb emotional processing by impeding global information processing (Schmid, Schmid Mast, Bombari, Mast, & Lobmaier, 2011).

Table 3 Determinants of affective processing

Factors	Effect
Handedness	Right-handed individuals show more left hemisphere activation in speech and language comprehension (Toga & Thompson, 2003)
Gender	Females show more rapid reaction to emotional stimuli. Valence effect is greater in female, and arousal effect is greater in male (Lang, Greenwald, Bradley, & Hamm, 1993)
Age	Adults show more regulation on negative emotions, compared to younger individuals (Wood & Kisley, 2006)
Genetic Factor	Heredity plays an important role in structuring the cortex (Thompson et al., 2001)
Personality	More neurotic individuals showed more hemispheric asymmetry, and extravert individuals showed less activation of cortex (Gale et al., 2001)
Mood State	Highly disturbed mood affected enhanced lateralization (Lim et al., 2012)

2.3.2. Emotional Granularity

A personality factor that directly affects emotional process is emotional intelligence. Emotional intelligence helps successful integration of social signals to adequate social perception to construct proper social skills (Mayer & Salovey, 1995). Its definition could also be a self-awareness of emotion (Lane, Quinlan, Schwartz, Walker, & Zeitlin, 1990). In a similar line, Barrett and Gross defined ‘emotional granularity’ as "a tendency to report distinct emotional experiences with precision” (Barrett & Gross, 2001). Some people can describe their emotional experience as discrete emotions (e.g., anger, disgust, fear, joy, pride, awe), while others can only report in general affective state consisting of pleasant and unpleasant feelings (Barrett, Gross, Christensen, & Benvenuto, 2001). Granularity captures trait-level individual difference in cognition: people with high granularity may apply more complex conceptual knowledge to conceptualize their internal state, while people with low emotional granularity may experience emotion only as positivity-negativity. High granular people access and use their conceptual knowledge more efficiently to conceptualize affective state using greater working memory capacity (Barrett et al., 2004). Deterioration of negative feeling was faster in highly granular individuals (Sevdalis, Petrides, & Harvey, 2007). On the other hand, extremely low granularity, or failure of situational conceptualization may result in alexithymia (an inability to identify and name emotional states, Taylor & Bagby, 2000).

2.3.3. Implications for the Present Study

To the best of my knowledge, there is no EEG study that measured and modeled the impact of "emotional granularity". There are few studies linked "trait emotional intelligence" and brain activity. Jaušovec and Jaušovec (2005) studied event-related synchronization (ERS) and found that emotionally intelligent individuals show more gamma band activation and less upper alpha deactivation. Difference in cortical asymmetry has been proposed to be an indicator of different emotional intelligence (Mikolajczak, Bodarwé, Laloyaux, Hansenne, & Nelis, 2010). There are several fMRI studies done for spatial analysis of emotional intelligence (e.g., Kreifelts, Ethofer, Huberle, Grodd, & Wildgruber, 2010; Reis et al., 2007). Due to its low temporal resolution, however, early reaction to emotional element was hard to be identified. Furthermore, the emotional intelligence in these studies did not explicitly reflect the affective process, but rather studied about self-control or sociability. This fact adds significance to the present study. The present study will focus on emotional granularity, which is directly connected to the conceptualization of emotion. Personal variation in emotional granularity could be one of great topics in human factors area, because it has an impact on how people perceive, process, and behaves toward affective designs of systems. It can also mediate evaluation and choice behavior through working memory and decision-making (Lottridge et al., 2011).

2.4. Event-Related Potential (ERP)

There exist numerous feature extraction and translation techniques. Introduced here is ERP, which shows the intensity change of electrical activity on scalp. As the fluctuation of electrical power is represented on time domain, it benefits from high temporal resolution of EEG method.

Sudden onset of visual stimuli evokes prominent electrical peaks on scalp, and the increased ERP amplitude is considered to reflect the increased engagement of corresponding brain cortex and subsequent cognitive operations. Affective stimuli mostly generate different ERP amplitudes compared to neutral stimuli, with less change in peak latency (e.g., Palomba, Angrilli, & Mini, 1997; Thomas, Johnstone, & Gonsalvez, 2007). Many papers will be reviewed in this section, mainly about valence and arousal effects that have been reported. However, affective ERP modulations varied with experiment settings, such as recording methods, source of stimulus, task, as well as noise reduction methods. Also, worth to note is that the same name of ERP component in different literature does not necessarily indicate the same component. For example, P1 component was a positive between: 150-210ms, 125-225ms, 160-220ms, 120-315ms, 170-250ms, 180-230ms, and even 400-550ms. The present study used N1 and P1 for the peaks in 100-200ms range, N2 and P2 for the peaks in 200-300ms, P3 for a positive peak near 300ms, N4 for a negative peak near 400ms, and LPP for later components, usually between 400-600ms. EPN is a significant difference between P2 and N2 especially in posterior area. Figure 2 illustrates how these common ERP components appear on time (milliseconds) – amplitude (micro voltage) space.

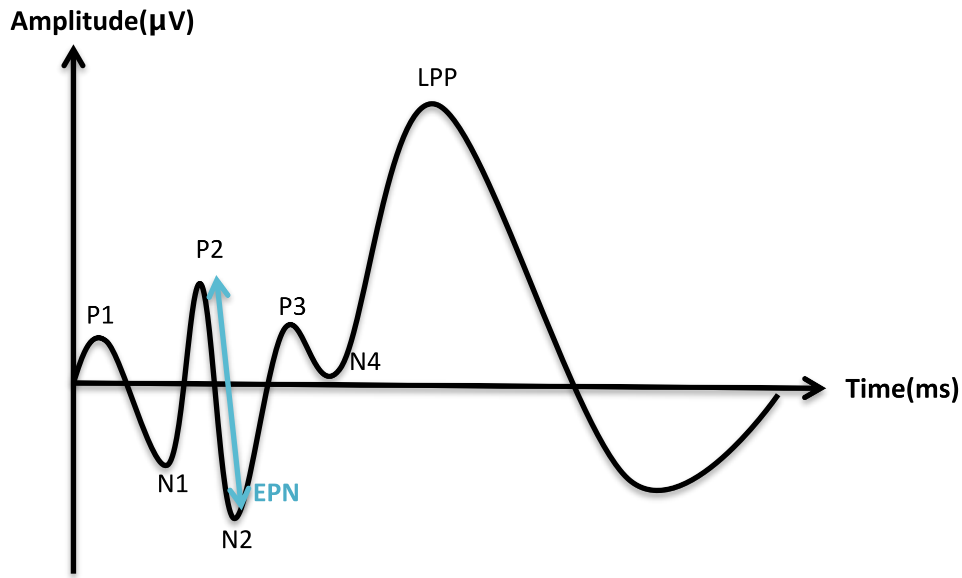


Figure 2 Typical ERP waveform and components in response to affective visual stimuli

In general, the effect of affective stimuli started early and generated early ERPs (around 170ms), primarily reflecting uncontrolled spontaneous perceptual processing. It is a common view that affective contents are processed after at least 100ms, although some researchers observed additional earlier ERP components (before 100ms) that are discriminable between emotions (e.g., Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Rigoulot et al., 2008). The amplitude grows stronger around 300ms through 700ms range, and remains consistent until around 850ms. These late ERPs are thought to reflect increased cognitive resource allocation facilitated by motivational relevance of cues (Codispoti, Ferrari, & Bradley, 2007). In terms of topography, frontal areas were involved in more complex cognitive processes such as evaluation of emotional valence (e.g., Davidson & Tomarken, 1989; Davidson & Irwin, 1999), and parietal areas were involved in analyzing emotional arousal (Heilman, Lane, & Nadel, 2000; Heller, 1993; LaBar & Cabeza, 2006). Olofsson, Nordin, Sequeira, & Polich (2008) is good for comprehensive ERP review.

2.4.1. Short Latency

Early components (N1 or P1 in 100-200ms range) are sensitive to perceptual factors of a stimulus. It indicates sensory processing within the visual cortex, such as the mapping of the distinctive object features (Balconi & Pozzoli, 2003). Thus, early components index structural elaboration of stimuli or selective attention (e.g., Batty & Taylor, 2003; Bradley, 2009; Junghöfer, Bradley, Elbert, & Lang, 2001; Schupp, Stockburger, Codispoti et al., 2007). This is not inconsistent with the results of some studies that found that emotional stimuli elicited larger positive amplitudes as opposed to neutral stimuli, in frontal area (e.g., Eimer, Holmes, & McGlone, 2003).

Threatening features, in specific, captured more attention (Codispoti, Ferrari, Junghöfer, & Schupp, 2006; Schupp et al., 2004). Fearful stimulus sometimes exhibited faster reaction than other emotional stimuli (Eimer et al., 2003). Threating stimulus was processed even when one was instructed to ignore the meaning of words (Thomas et al., 2007). Thus, it has been assumed that the greater potential of risk in negative affect (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001) engaged more attentional processing and had favored access to processing resources (Dolcos & Cabeza, 2002). The early ERP components were also sensitive to erotic images (De Cesarei & Codispoti, 2006; Flaisch, Junghöfer, Bradley, Schupp, & Lang, 2008; Schupp, Junghöfer, Weike, & Hamm, 2003). However, there exists controversy in whether the early components' different reaction to negative and positive is due to stimulus' emotional contents or due to visual features. Also, the studies failed to show distinctive neural patterns for other discrete emotions in early stage.

The early reactions were not voluntary but very quick, effortless, autonomic, and coarse evaluation process initiated by frontal lobes (Comerchero & Polich, 1999; Knight & Nakada, 1998). Harman, Rothbart, & Posner (1997) proposed that attentional priming of the visual area is the result of projections from cingulate cortex. Amygdala might facilitate this short response latency (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004), because it receives early visual inputs (LeDoux, 2000) and interacts with many attention-related areas of the brain, including the prefrontal region (Vuilleumier, Armony, Driver, &

Dolan, 2003). Sabatinelli, Lang, Bradley, Costa & Keil (2009) suggested that amygdala and inferior temporal cortex differentiate emotional from non-emotional scenes. Overall, affective content are analyzed causing the reorientation of attention and direct the later process (Delplanque, Silvert, Hot, Rigoulot, & Sequeira, 2006).

2.4.2. Middle Latency

Middle ERP components (N2 or P2 between 200-300ms) represent selection processes. Especially, the P2 is one of the visually evoked response patterns associated with the analysis of higher-level visual features guided by attention (Luck & Hillyard, 1994). Selective attention to task related features or biologically relevant properties lead to the process of arousal and hedonic value of emotional stimuli (Balconi & Pozzoli, 2003). Due to the P2 component's reaction to salient stimulus, or strongly affective stimulus, previous research has indicated that this component may originate in the anterior cortices (Potts & Tucker, 2001).

The negative peak around 300 ms (N2) also has been proposed as a good candidate of discovering emotional effects (Carretié, Iglesias, Garcia, & Ballesteros, 1997). Enhanced negativity appeared significantly at lateral temporal and occipital electrodes. For example, fearful images showed enhanced negativity in lateral posterior area (Eimer et al., 2003). This increased early posterior negativity (EPN) was mainly elicited by highly arousing stimuli (Schupp et al., 2004; Schupp, Flaisch, Stockburger, & Junghöfer, 2006a; Schupp, Junghofer, Weike, & Hamm, 2003) and was correlated modestly with signal modulations in the amygdala and anterior cingulate cortex (ACC) (Sabatinelli, Keil, Frank, & Lang, 2013). Asymmetry was not yet apparent in these early stages, although reported inconclusively (De Cesarei & Codispoti, 2006; Keil et al., 2001).

2.4.3. Long Latency

2.4.3.1. P300

One of the main late components is P3 (or P300), a broad positivity over cortex that takes place before or sometimes overlap with the late positive potential (Linden, 2005). The peak happens over parietal area, associated with target processing (Sabatinelli, Lang, Keil, & Bradley, 2007). It has been suggested to be the result of various cognitive functions such as: short-term memory storage (Palomba et al., 1997; Polich, 2007), contents evaluation (Knight, 1997; Soltani & Knight, 2000), and decision-making processes (Nieuwenhuis, Aston-Jones, & Cohen, 2005). In previous emotion studies, higher amplitude of P3 was obtained from highly emotional and arousing stimuli (e.g., Conroy & Polich, 2007). Highly arousing pictures were perceived to be more interesting, and been remembered better (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000), as they potentiated attention (Schupp et al., 2007). Although it was observed that the negative and positive stimuli shared some cognitive resources, negative emotions obtained a higher processing priority and take up processing capacity (Meinhardt & Pekrun, 2003). Other than emotional factors, intentional attention or perceived importance of stimulus further intensified the amplitude of P3, while non-evaluative categorization task decreased the amplitude of P3 (Kok, Ridderinkhof, & Ullsperger, 2006; Ridderinkhof, van der Molen, Maurits W, Band, & Bashore, 1997). Prior experiences were reflected in the P3-related physiologic activity. For example, maltreated children showed larger P3 amplitude when they attended to angry face, opposed to happy targets (Pollak, Cicchetti, Klorman, & Brumaghim, 1997). It indicated that P3 is more controlled stages of processing (Thomas et al., 2007). Thus, suggested was that P3 is related to more cognitive implications than to affective processes in some studies (Carretié, Iglesias, Garcia, & Ballesteros, 1997).

2.4.3.2. N400

Another late component is N4 (or N400; between 200-600 ms), which is linked to meaning processing, or the integration of meaning extracted from multiple modalities (see Kutas & Federmeier, 2011). This component has been mostly debated in studying language perception, because its amplitude was reported to be sensitive to meaning processing. But turned out was that it is not a localizable mental operation but a distributed system that is opened to all stimuli in all task conditions. N4 integrates lexical information into a semantic representation (Van Berkum, Hagoort, & Brown, 1999), and this representation interacts with previous semantic memory (Laszlo & Federmeier, 2011). Emotional valence also contributed to this semantic process (Schirmer & Kotz, 2003).

2.4.3.3. Late Positive Potential

A component that appears later and lasts long with widely distributed positive peak amplitude is commonly found and called the late positive potential (LPP) (Schupp et al., 2000). The amplitude of LPP was related to memory performance and other top-down processing in many studies (e.g., Azizian & Polich, 2007). In emotion studies, emotionally arousing pictures elicited larger LPPs (Codispoti, Mazzetti, & Bradley, 2009; Cuthbert et al., 2000; Schupp, Flaisch, Stockburger, & Junghöfer, 2006), particularly greater amplitude in left centro-parietal area to negative words (Inaba, Nomura, & Ohira, 2005). Some kind of emotional regulation (lower LPP) was also observed in older adults group (Wood & Kisley, 2006), suggesting controlled top-down process in this time frame. On the other hand, Carretie et al. (1997) found that increased ERP amplitude evoked motor effects as well as perceptual processes. A recent EEG and fMRI study revealed that LPPs represent the collective activity of visual cortex (Sabatinelli et al., 2013) and are supported by the iterative feedback from subcortical to cortical sites, resulting in a series of attention orienting, metabolic mobilization, and action preparation (Lang & Bradley, 2010; Pessoa & Adolphs, 2010; Vuilleumier, 2005), with combined activity of striate cortex, inferior temporal cortex, and medial parietal cortex (Sabatinelli et al., 2007).

2.4.4. Implications for the Present Study

ERP components show the people's behavior in the neural level. We could directly notice how individuals actually perceived the stimulus, how fast they reacted, and to what extent the stimulus impacted the person.

Since aforementioned studies have employed a variety of stimuli (e.g., Balconi & Pozzoli, 2003 (facial expression); Huang, Lee, & Federmeier, 2010 (words); Spreckelmeyer, Kutas, Urbach, Altenmüller, & Münte, 2009 (audio)), experiment methods (e.g., Delplanque et al., 2006 (fast categorization); Keil et al., 2002 (passive viewing); Meinhardt & Pekrun, 2003 (oddball task)), and analysis methods (peak amplitude, average amplitude around peak, etc.), they showed variable ERP outcomes. Nonetheless, each components and associated functions have been illustrated through a large number of experiments. Table 4 summarizes common conclusion of previous studies, and more ERP experiments are listed in Appendix H.

Table 4 ERP components and related cognitive processes

ERP components	Related processes	Control	Location
Early components (100-200 ms)	• Mapping distinctive perceptual features (e.g., face), evaluation of stimulus, selective attention to emotional feature	Involuntary stage	Prefrontal region; amygdala and visual cortex
Middle components (200-300 ms)	• Higher level selection process • Early posterior negativity (EPN) appears here		Lateral temporal and occipital area; anterior cortices and amygdala
P300	• Target processing (evaluating importance and making decisions), short-term memory storage	Controllable Stage	Broad over cortex
N400	• Integration of semantic information, accessing previous memory		Prefrontal, inferior temporal, and middle and superior temporal area
Late positive potential (LPP)	• Memory, top-down process, motor preparation		Striate, inferior temporal, and medial parietal cortex

If the emotional process follows constructionist approach, we can infer which ERP component corresponds to which stage of emotional process by matching each stage of the constructionist model and the functions of ERP components, based on the previous knowledge. Figure 3 below shows the proposed matching of stages: the early components might correspond to the formation of core affect, and the late components might match to the situated conceptualization.

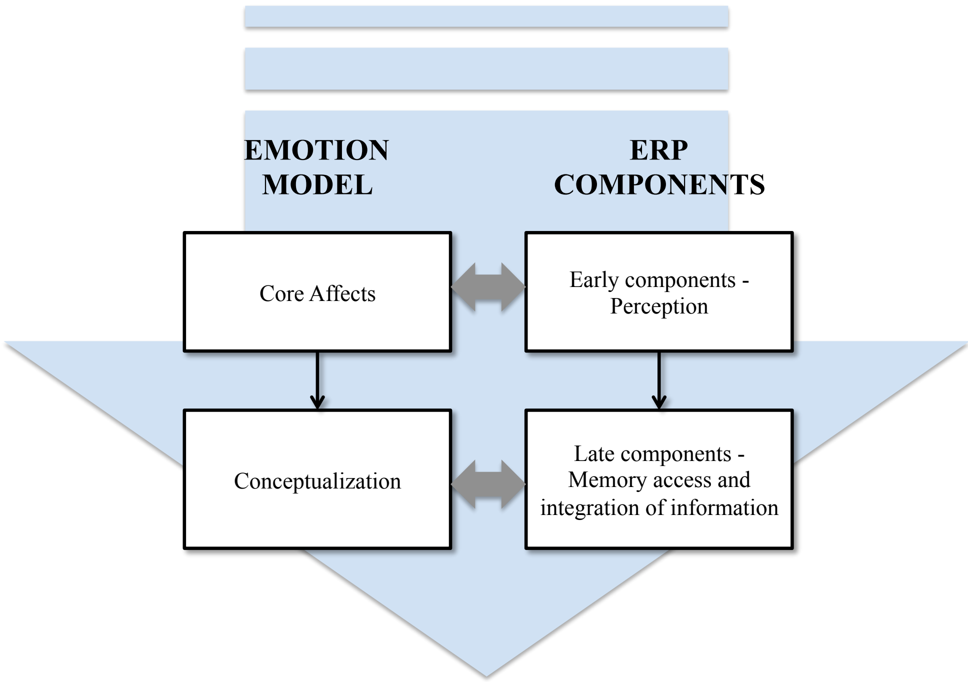


Figure 3 Constructionist emotion model and corresponding ERP components

2.5. Coherence

EEG activity shows difference oscillation in at various frequency bands, and each frequency band react differently to emotional stimuli. Coherence is the measure that shows the strength of synaptic connections between two distant brain regions within certain frequency bands. This long-range dynamic synchrony between groups of neuronal assemblies is thought to be an important central mechanism of information processing between multiple brain areas that help spontaneous functioning of brain (Bhattacharya, Petsche, Feldmann, & Rescher, 2001). High coherence is often interpreted as dependency, correlate of cognitive processing (Thatcher, Krause, & Hrybyk, 1986), anatomical connections (Fein, Raz, Brown, & Merrin, 1988), temporal correlation (Singer & Gray, 1995), mutual information exchange (Petsche & Rappelsberger, 1992), and functional cortical integration (Maurits, Scheeringa, van der Hoeven, & de Jong, 2006), whereas low coherence means functional isolation of brain regions associated with a cognitive task (Weiss & Mueller, 2003).

2.5.1. Theta Band (4-8 Hz)

Coherence measurement is specific to frequency bands. In general, low frequency bands reflect attention and working memory processes in frontal and parietal areas (Jensen & Tesche, 2002; Klimesch, 1999). Theta rhythm is thought to be responsible for the encoding of new information (Klimesch, Doppelmayr, Russegger, & Pachinger, 1996) and emotional process, especially fear conditioning (Knyazev, 2007; Putman, van Peer, Maimari, & van der Werff, 2010). Some studies reported early synchronization of theta wave when participants are viewing emotional images (Aftanas & Golocheikine, 2001; Balconi & Pozzoli, 2009; Balconi, Brambilla, & Falbo, 2009; Knyazev, Levin, & Savostyanov, 2008), listening to music (Sammler, Grigutsch, Fritz, & Koelsch, 2007), and watching films with emotional content (Jausovec, Jausovec, & Gerlic, 2001).

2.5.2. Alpha Band (8-13 Hz)

In the early stage of EEG study, Ray and Cole reported that alpha power (or mu) is related to attentional demand (Ray & Cole, 1985). Alpha power mostly decreases when cortical excitability and engagement in stimulus processing increases (e.g., Andrew & Pfurtscheller, 1996; Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Klimesch, Sauseng, & Hanslmayr, 2007; Sauseng & Klimesch, 2008). Therefore, as task gets complex and requires more attention, the magnitude of alpha suppression increases. Recently proposed theory suggests that alpha band is related to the disengagement of task-irrelevant brain areas (Palva & Palva, 2007). In emotion research, high coherence of theta and alpha band in fronto-parietal area reflected central executive function of working memory (Sauseng, Klimesch, Schabus, & Doppelmayr, 2005).

2.5.3. Beta Band (13-30 Hz)

Beta band is classically considered as being related to sensorimotor and motor functions (e.g., Baker, Olivier, & Lemon, 1997; Kilner, Baker, Salenius, Hari, & Lemon, 2000; Sanes & Donoghue, 1993). It can also reflect the expectancy of or decision about forthcoming event (Donner, Siegel, Fries, & Engel, 2009). On the perceptual-cognitive side, recent studies associated beta rhythm with attentional top-down processing that predominate the effect of novel external events (von Stein, Chiang, & Konig, 2000). It is capable of long-distance coupling (Schnitzler & Gross, 2005). Based on these characteristics, Engel and Fries (2010) suggested that beta rhythm is related to the maintenance of status quo, the current cognitive or sensorimotor state.

2.5.4. Gamma Band (30-50 Hz)

Recently gamma wave (30 Hz and higher) has captured most attention. It was observed that gamma oscillations are related to a broad range of processes such as feature integration, attention, stimulus selection, integration sensory inputs and sensorimotor activities, movement preparation, and memory formation (Engel, Fries, & Singer, 2001; Jensen, Kaiser, & Lachaux, 2007; Knyazev, 2007; Senkowski, Schneider, Tandler, & Engel, 2009) were affected by gamma rhythm. It also showed increased power in visual stimulation task or movement tasks (Murthy & Fetz, 1992; Pfurtscheller, Graimann, Huggins, Levine, & Schuh, 2003). These faster oscillations might serve active information processing by actively coupling cell assemblies over spatially separated regions and binding attributes and object representations (Tallon-Baudry & Bertrand, 1999; Varela, Lachaux, Rodriguez, & Martinerie, 2001). In emotion study, the 30-50 Hz band showed more power over left hemisphere for negative valence and more power of right hemisphere for positive valence. In particular, right frontal electrodes showed enhanced gamma power for emotional pictures (Keil, Muller, Ray, Gruber, & Elbert, 1999). Li and Lu (2009) successfully classified people watching happy and sad facial expressions with 93% accuracy using gamma band power.

2.5.1. Implications for the Present Study

It is relatively clearer that different frequencies reflect global activity of the brain. It has been suggested that lower frequency bands below 30 Hz support large-scale functional coupling of neurons than high frequency bands over 30 Hz. However, we do not yet have a conclusive answer on why the brain oscillates at such a diverse range of frequencies and how these different oscillatory processes functionally complement each other, and these effects can be modulated by individual traits such as gender, personality, and implicit/passive condition of tasks. In addition, it is very difficult to directly associate oscillatory activity to a unique cognitive function. Still, studying coherence will help us picture the coherent activity of different brain regions and corresponding functions. Table 5 is a brief summary of functions of each frequency band.

Table 5 Frequency bands and related cognitive functions

Frequency Band	Functions
Theta (4-7 Hz)	Encoding of new information, fear conditioning
Alpha (8-12 Hz)	Attention, working memory, disengagement of task-irrelevant brain areas
Beta (13-30 Hz)	Sensorimotor and motor functions, maintaining status quo
Gamma (30-50 Hz)	Integration of information

2.6. Research Questions and Hypotheses

Research question 1 and 2 are related to the model of emotion. The present study tried to find evidence of constructionist emotion model, by using discrete emotional category for emotional evocation. Research question 3 and 4 are about how individual difference in emotional granularity influences emotional process.

- **Research Question 1:** Do different emotional contents undergo different neural process? Which emotion model better explains the neural process of emotion?
  - **Hypothesis 1:** In order to support the constructionist model and reject locationist model, the activation of specific brain region will not be dependent on discrete emotions. In other words, there will be no interaction effect between discrete emotion and brain locations.
  - **Hypothesis 2:** The ERP components will show difference between emotions, reflecting discrete emotional processing.
- **Research Question 2:** How does the emotional granularity influence the emotional processes?
  - **Hypothesis 3A:** The early ERP components will not show granularity effect.

- **Hypothesis 3B:** The late ERP components will show granularity effect because granularity requires higher-level cognitive process of labeling affective states. More granular individuals will demonstrate greater reaction to each ERP component.
- **Hypothesis 4:** Granularity will have effect on coherence distribution, especially those associated with emotional regulation. Highly granular person will show greater change of coherence between two brain areas, through where affective experience is controlled.

2.7. Summary

Growing efforts are in progress to understand human emotions, one of the most complex and important human experiences. Emotion models provided cognitive model of emotion, and neural study have been actively conducted to find brain bases of emotion. However, very little EEG studies considered the process of discrete emotions and individual differences that take important part in the process. This study conducted an experiment in order to address a possible neural model of emotion process and find implications for neuroergonomics area.

3. METHODOLOGY

3.1. Participants

The total of 28 participants from a local university participated in the EEG experiment. The population was restricted to male to avoid sex difference confounds (e.g., Kring & Gordon, 1998). All participants were asked to finish online survey on the day before the EEG recording, and also finish a stimulus rating survey after the EEG recording. They were compensated with class credit, and all subjects signed an informed consent form prior to the beginning of the EEG recording. The Institutional Review Board at NCSU approved the human study protocol. See appendix C for the approved IRB approved consent form.

Out of 28 male participants, 8 were excluded from the data analysis, in order to avoid unexpected distortion of data. Three participants were excluded from analysis based on the online survey results: one left-handed or ambidextrous participant and two anxious / depressed participants (were moderately anxious or had potential of concern or more than mildly depressed). These participants were screened because handedness influences the lateralization of brain (Toga & Thompson, 2003), and high anxiety and depression exhibit greater reaction to negative images than those who are not (Oathes et al., 2008; Lang, Bradley, & Cuthbert, 1998). One participant stated attention deficit hyperactivity disorder (ADHD) and his data was also removed. There were four participants removed due to data recording errors. As a result, brain signals from 20 right-handed male participants without severe anxiety or depression were analyzed. The average age of 20 participants was 21.05 years and standard deviation was 1.19 years.

3.2. Apparatus

3.2.1. Online Survey

All participants completed online survey on the night before the EEG data collection. An online survey platform 'Qualtrics' was utilized for participants' convenience. The participants obtained the link to the surveys via email, and were instructed to complete the survey on the day before EEG recording. They could stop answering the questions anytime they want, and could come back later to the same page as long as they use the same computer and browser. Data from all participants were saved in one file and analyzed with R, a language and environment for statistical computing and graphics from GNU Project. Table 6 shows which survey collected which information. See Appendix D for the survey details and section 3.3.1 for calculating granularity from DRM survey. The survey was anticipated to take approximately 45 minutes to complete.

Table 6 Online surveys

Information collected	Surveys
Gender and age	Demographic survey
Handedness	Edinburgh Handedness Inventory (EHI, Oldfield, 1971)
Anxiety level	Beck Anxiety Inventory (BAI, Beck & Steer, 1991)
Depression level	Beck Depression Inventory (BDI, Beck, Steer, & Carbin, 1988)
Emotional Granularity	Day Reconstruction Method (DRM, Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004)

3.2.2. Experimental Stimuli

3.2.2.1. IAPS and Mikels' Norm

Images from IAPS, a widely used standard emotional stimuli database, were used. First, emotional stimuli that induce one particular emotion were selected, based on Mikels' norm (Mikels et al., 2005). Awe, excite, fear and disgust were chosen as discrete emotion categories, because these categories were more discriminable from each other than other categories. Second, from the reduced set, images with similar valence and arousal value were selected. As a result, a total of 50 images were selected (10 images for each of 5 emotional categories; awe, excitement, fear, disgust, and neutral). Examples from five emotions are presented in the Figure 4.

Figure 4 Examples of IAPS images for each discrete emotion

Valence and arousal of each image is plotted in the Figure 5. Negative images had low valence and high arousal. Positive images had high valence and high arousal. Awe and Excite images were not differ in valence ($t(9)=-0.8025$, $p=0.4429$) but differ in arousal ($t(9)=-3.6058$, $p=0.0056$).

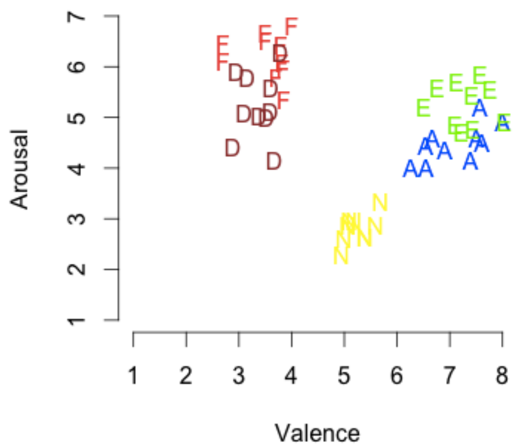
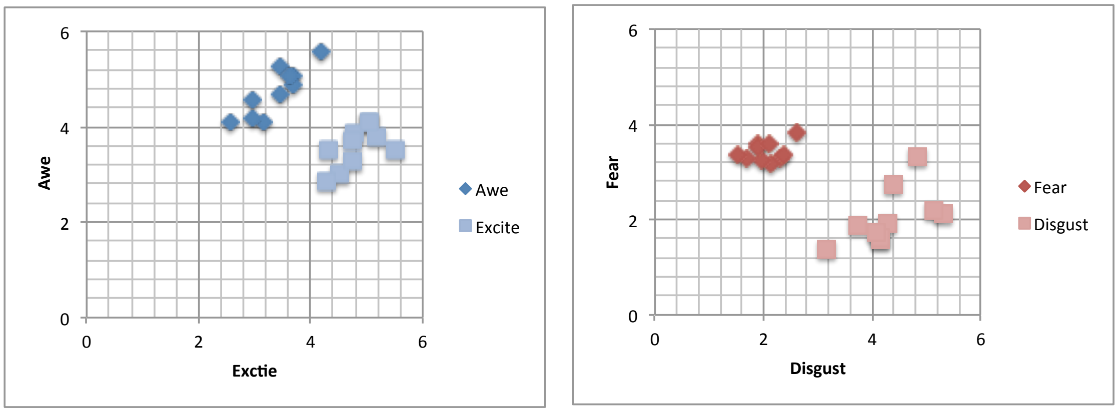


Figure 5 IAPS images on valence-arousal space (A: Awe, E: Excitement, F: fear, D: disgust, N: neutral)

They were visually distinguishable when plotted on excite-awe space (Figure 6 (a)). Fear and disgust images were also not differ in valence ($t(15.888)=0.9816$, $p=0.341$) but differ in arousal ($t(15.642)=3.8525$, $p=0.0014$). They were also visually distinguishable when plotted on disgust-fear space (Figure 6 (b)). Arousal was higher in negative stimuli when compared to positive stimuli ($t(35.09)=-4.1067$, $p=0.0001$). See Appendix E for more information about stimuli.



(a) (b)

Figure 6 Discrete emotion scores from Mikels' norm (2005): (a) awe and excite, and (b) fear and disgust

3.2.2.2. Validation of Stimuli

We needed to validate the use of stimuli. First, in order to see if emotional stimuli chosen from IAPS and discrete emotion assigned to each image based on Mikels' norm successfully evoked intended emotion to participants, a survey was done after the EEG data collection. The participants completed a survey that asked what emotion they felt while they were watching each image on the TV screen. They chose one emotional word from neutral, awe, excite, fear, and disgust, and specified the strength of selected emotion (on a 0 to 6 scale). If they could not find an emotional word that fits their experience, they were allowed to leave it blank or write down an alternative emotion. If they did not to answer, chose more than two words, or indicated other emotion, the response was discarded. If a participant rated the image as intended, it was considered successful elicitation of the emotion. The proportion of successful elicitation was calculated over participants to validate the emotion that each picture induces. Table 7 shows what percentages of images were successful in producing the emotion from Mikels' norm (2005). Not all images could evoke intended emotion to all participants. However, the majority of images elicited intended emotion to most of the participants.

Table 7 Intended emotions based on Mikels' norm and the percentage of perceived emotion for each discrete intended emotion

		Perceived Emotion				
		Awe	**Excite**	**Fear**	**Disgust**	**Neutral**
Intended Emotion (Mikels' norm)	**Awe**	**72.5%**	8.5%	0.0%	0.0%	19.0%
	Excite	8.0%	**65.0%**	1.0%	0.0%	26.0%
	Fear	22.0%	6.0%	**52.5%**	1.5%	17.5%
	Disgust	9.0%	6.0%	7.0%	**63.0%**	14.5%
	Neutral	13.5%	4.5%	2.0%	0.5%	**79.5%**
Average level of emotion (0-6)		2.99	2.80	2.65	3.20	N/A

Second, visual feature of chosen image is a potential factor that can affect brain activity. A mini online survey with 25 participants (not overlapping with this experiment) was done with the same online survey platform 'Qualtrics', in order to see if images in discrete emotion categories have different visual characteristics. Each participant rated 'complexity' and 'dynamicity' of all 50 images, because it was reported that figure-ground images and scene affect early ERP components around 150ms (Bradley, Hamby, Low & Lang, 2007), and dynamic actions in pictures enhance movement-related brain areas (Riva & Zani, 2009). The result of this survey was used in section 5.1.1.

In the survey, they were asked, "please rate this picture: this picture is simple/complex", and asked to chose the level among five numbers, "1: very simple, 5: very complex". Again it asked, "this picture is static/dynamic", and asked to rate using five numbers again, "1: very static, 5: very dynamic".

One-way ANOVA was used to compare emotions in terms of 'complexity' and 'dynamicity'. ANOVA for complexity showed that the visual complexities of stimuli were diverse ($F(4, 45) = 11.78$, $p < .0001$). Pairwise comparison (Tukey post-hoc) indicated that neutral images were simpler than disgust (p<.0001), excite (p<.0001), fear (p=0.0003), and awe (p=0.0343). On the other hand, disgust was complex than neutral (p<.0001) and awe (p=0.0091). In addition, ANOVA for dynamicity exhibited stimuli in each discrete emotion category varied in terms of dynamicity ($F(4, 45) = 32.67$, $p < .0001$). In short, there were three levels of dynamicity level: fear and excite were most dynamic, disgust and awe were less dynamic, and neutral was the most static. In detail, neutral stimuli were static than excite ($p<.0001$), fear ($p<.0001$), disgust ($p<.0001$), and awe ($p=0.0027$). Awe was more static than excite ($p<.0001$) and fear ($p<.0001$). Excite and fear was more dynamic than disgust ($p<.0001$). Figure 7 shows the result of the survey. Each error bar is constructed using 1 standard error from the mean.

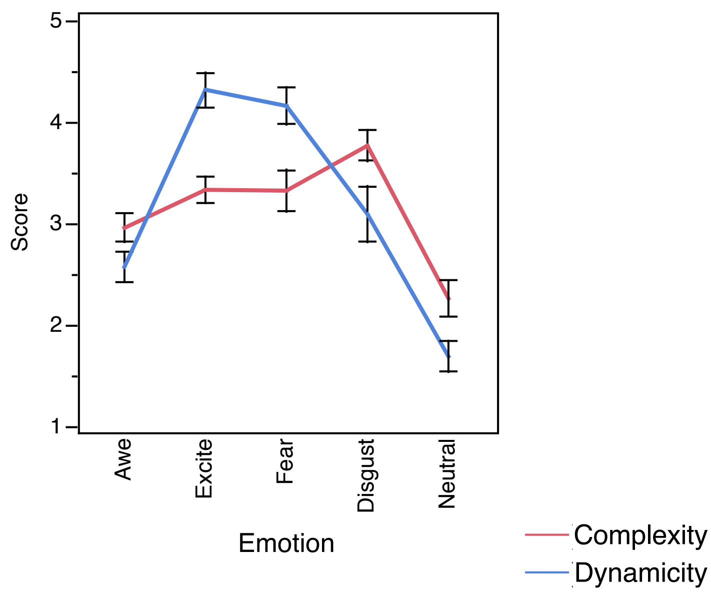


Figure 7 Averaged complexity and dynamicity score of images in each emotional category: blue line represents dynamicity from 1 (very static) to 5 (very dynamic), red line represents complexity from 1 (very simple) to 5 (very complex).

3.2.3. EEG Measurement System and Analysis

3.2.3.1. EEG Recording

Signal was amplified with a g.USBamp amplifier from g.tec Medical Engineering, band-pass filtered between 0.1 Hz and 60 Hz, notch filtered at 60 Hz, and digitized at a rate of 256 Hz, using g.tec LabVIEW modules. For higher conductivity, Ag/AgCl gel was applied between electrodes and scalp. Figure 8 is a screenshot of LabVIEW program developed for EEG recording. Part A was displayed on a 42" television and showed images on a full-screen. Part B and C were displayed on a researcher side's screen. Part B was used to enter participant's information and overview the status experiment, and part C displayed amplitude of each electrode.

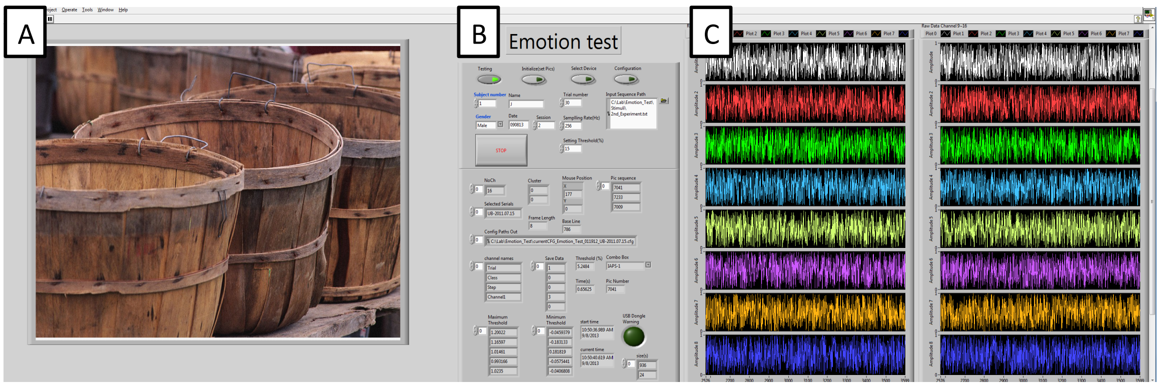


Figure 8 Front panel of EEG recording program

The participants were seated in a comfortable chair in front of the TV, 50" from the TV. Participants wore an EEG cap embedded with 16 electrodes covering Fp1/Fp2, F7/F8, FC3/FC4, T7/T8, P7/P8, FT7/FT8, P3/P4, C3/C4 area, based on the modified 10-20 systems of the International Federation (Jasper, 1958; Niedermeyer & da Silva, 2005). Fpz was used as a ground, and left ear lobe was used as a reference. The areas were chosen based on the Brodmann Area (BA), the list of cerebral cortex areas defined by corresponding functions. Table 8 shows channel numbers, 10-20 locations, corresponding BAs, anatomical locations with functional names, and their functions, derived from meta-analyses of the neuroimaging literature on emotion (e.g., Kober et al., 2008; Lindquist et al., 2012). For montage detail of channels, refer to the Figure 9.

Table 8 Channels and their functional locations

Channels	10-20 Location	BA	Location	Primary Functions
1/2	Fp1/Fp2	11/12	Medial orbitofrontal (ventromedial prefrontal cortex)	Affect generation and representation; visceromotor control
3/4	F7/F8	47	Lateral orbitofrontal	Integration of core affect and contextual information
5/8	FT7/FT8	38	Temporopolar cortex (anterior temporal lobe)	Conceptualization (may also index affective salience due to proximity to amygdala)
6/7	FC3/FC4	6	Supplementary motor cortex	Motor preparation
9/12	T7/T8	22	Superior temporal cortex	Conceptualization
10/11	C3/C4	43	Subcentral	Core affect representation (close to posterior insula)
13/16	P7/P8	37	Occipitotemporal cortex	Visual perception; attention to affectively salient stimuli
		39	Angular gyrus	
14/15	P3/P4	40	Supramarginal gyrus	Conceptualization

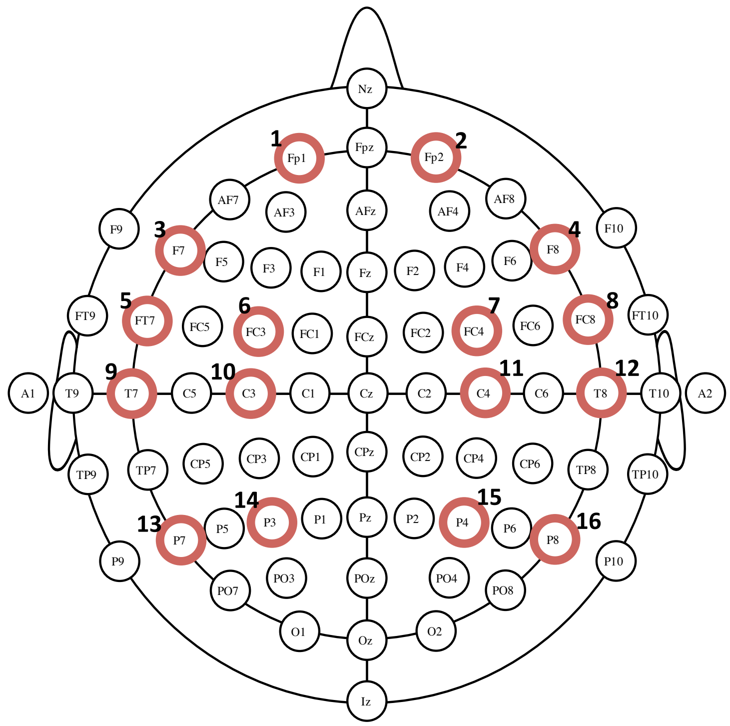


Figure 9 Montage

Each of 50 images was presented for 3 seconds, after 2 second of cross fixation. After the presentation period, a participant took rest for 10 seconds. If the participant's brain activity calmed down (more than 95% were within the threshold calculated by brain activity during the rest state), next image showed up after another cross fixation. If more than 5% of signals are outside the threshold, the participant was given maximum 20 seconds of additional rest period. After one session is finished, the participant took 3 minutes rest, and the identical second session started. The image presentation order was awe, excitement, fear, disgust, and neutral.

3.2.3.2. EEG noise filtering

Amplified EEG data collected from scalp electrodes have some signal distortions. These artifacts show different shape and higher amplitudes when compared to uncontaminated signals. It can be patient-related (e.g., minor body movements, pulse, eye movements, sweating, etc.) or technical (AC power line noise at 50/60 Hz, impedance fluctuation, too much gel or dried electrodes, etc.) (Teplan, 2002). In this experiment, trials with amplitude exceeding ±35 μV measured after stimulus onset were excluded from analysis. The threshold 35 μV is an average of 99.7% confident intervals of all participants. Each confidence interval was calculated by sampling all data points collected during -200 ms ~ 1000 ms epoch and estimating μ±3σ. This value was enough to remove the effect of eye blinks that causes voltage over 60 μV.

Collected EEG data underwent Common Average Reference (CAR) calculation, where average amplitude of signals from every electrode site was used as a reference. This was to detect artifacts caused by electromyography (EMG) or electrocardiography (ECG), as earlobe reference is less likely to sense these noises. An isolated single unit activity does not appear on the CAR, except when the signal is so large and dominates the average (see Ludwig et al., 2009 for a good review). New amplitude was computed using the CAR formula below. V_i represented the amplitude between the ith electrode and the earlobe reference.

$$V_i^{CAR} = V_i - \frac{1}{n}\sum_{j}^{n} V_j$$

For zero-adjustment, average amplitudes during the 60 seconds of ‘baseline’ window (c_i) was subtracted from corresponding electrodes.

$$V_i^{Zero} = V_i - c_i$$

More filtering and feature extraction methods are well listed in a paper from Signal Processing Workshop in BCI Meeting 2005 (see McFarland, Anderson, Muller, Schlogl, & Krusienski, 2006).

3.2.3.3. *Event Related Potential (ERP) Components*

As ten images from each of five emotional categories were repeated twice, there were 100 epochs for each participant in total and 20 epochs for each discrete emotion. One epoch started 200 ms before the stimulus onset (0 ms) and lasted until 1000 ms after the stimulus onset. Noises were assumed to have an average of zero. Thus an average of twenty epochs in one emotion category became the representative ERP for the emotion. ERP features (amplitudes and latencies of N1, P2, N2, P3, N4, LPP) were than extracted. The letter P or N indicates polarity, and the number indicates the latency in hundred milliseconds. The components in this experiment were determined after data collection. See section 4.1.

3.2.3.4. *Coherence*

The objective of coherence analysis is to find correlated cortex areas while the participant is watching an emotional image stimulus. The EEG signal was band-pass filtered to get following four frequency bands: theta (4-7 Hz), alpha (8-12 Hz), beta (13-30 Hz), and gamma (30-50 Hz). Once filtered, epochs staring from -1000ms to 1000ms were obtained from all trials. This epoch was again divided into two: 1000ms before the stimulus onset and 1000ms after the stimulus onset. The epoch was determined to focus on the short effect of emotion within 1000ms, just like ERP. The total of 120 ($\binom{16}{2} = 120$) pairwise comparisons of two channels, X and Y, were be done by Welch method using the following equation. $P_{xx}(f)$ and $P_{yy}(f)$ are the power spectrums of x and y, and $P_{xy}(f)$ is the cross power spectrum of x and y. The formula returned coherence value over frequency.

$$C_{xy}(f) = \frac{\left|P_{xy}(f)\right|^2}{P_{xx}(f) * P_{yy}(f)}$$

The coherence data during 1000ms before the stimulus onset was subtracted from the coherence data of 1000ms after stimulus onset “coherence change”, and was used as a dependent variable.

In specific, beta band coherence of prefrontal and parietal were analyzed. Dorsolateral prefrontal cortex (DLPFC) in Fp1 and Fp2 region plays a role in emotion regulation by modulating posterior perceptual area and sending information to the amygdala (Eippert et al., 2007). The frequency band of interest was beta band (13-30Hz), since beta band oscillation mediates long distance coupling (Schnitzler & Gross, 2005) and attentional top-down processing (von Stein et al., 2000). The calculation was done separately in order to show lateralized effects proposed in previous research (Miskovic & Schmidt, 2010; Reiser et al., 2012). Coherence changes of Fp1 and electrodes on left hemisphere (T7, C3, P3, P7) were averaged to summarize interaction within the left hemisphere. Likewise, coherence changes of Fp2 and electrodes on right hemisphere (T8, C4, P4, P8) were averaged to find connectivity changes within the right hemisphere.

3.3. Experiment Design

3.3.1. Independent Variables

The effect of (a) discrete emotions, (b) brain regions, and (c) emotional granularity were studied throughout the study. Discrete emotions (a) and the results of validation are explained in section 3.2.2. For brain regions (b), refer to the Figure 9.

The (c) emotional granularity was measured based on the results of modified day reconstruction method (Kahneman et al, 2004 modified by Rice & Lindquist, unpublished). The participants were asked to recall up to five episodes from morning, five episodes from afternoon, and five episodes from evening of the day before the survey. For each episode, they were asked: what they were doing, where they were, and whom they were interacting with. Finally, they indicated to what level (from 0 to 6) they experienced each of twenty emotions while they were experiencing the episode. Table 9 shows the emotional words used in this survey. As a result, they rated 20 emotions during up to 15 episodes. See appendix D for more details .

To quantify the granularity, average intraclass correlations (ICCs) (Shrout & Fleiss, 1979) were calculated from self-reported emotional states of participants (Tugade et al., 2004). ICC of positive emotion words and ICC of negative emotion words were separately calculated for each participant. Low ICC value indicates that the participant can differentiate discrete emotional categories and express their emotional experiences with different emotion terms. On the other hand, high ICC value means that the participant use terms interchangeably to communication their emotional state. Thus, the ICCs were subtracted from 1 for ease of interpretation to make higher values correspond to more differentiation, or granularity. Positive granularity and negative granularity was then averaged to make a single granularity value.

Table 9 Emotion words used to measure emotional granularity

Positive	Negative
Amusement, awe, contentment, excitement, gratitude, happiness, love, pleased, pride, serenity	Anger, boredom, disgust, dissatisfied, downhearted, embarrassment, fear, gratitude, sadness, tired

The participants' average positive granularity was 0.81 (*SD* = 0.13) and the average negative granularity was 0.81 (*SD* = 0.14). Table 10 shows each individual's age and granularity score.

Table 10 Participants' information. All participants here are right-handed male without severe anxiety or depression.

Participant #	Age	Positive Granularity	Negative Granularity	Average Granularity
1	21	0.98	0.80	0.89
2	21	0.95	0.90	0.92
3	21	0.70	0.79	0.75
4	20	0.72	0.88	0.80
5	23	0.88	0.96	0.92
6	21	0.87	0.72	0.80
7	25	0.89	0.53	0.71
8	21	0.81	0.85	0.83
9	20	0.89	0.73	0.81
10	20	0.74	0.72	0.73
11	21	0.44	0.60	0.52

Table 10 continued

12	21	0.79	0.89	0.84
13	21	0.87	0.96	0.91
14	21	0.62	0.90	0.76
15	20	0.80	0.56	0.68
16	20	0.84	0.94	0.89
17	22	0.85	0.94	0.89
18	20	1.01	0.96	0.98
19	21	0.75	0.67	0.71
20	25	0.61	0.83	0.72
Average	**21.05**	**0.81**	**0.81**	**0.81**
SD	**1.19**	**0.13**	**0.14**	**0.11**

3.3.2. Dependent Variables

Dependent variables were EEG response to emotional stimuli: amplitudes and latencies of six ERP components (N1, P2, N2, P3, N4, LPP in this experiment) and coherence of cortex areas (in theta (4-7Hz), alpha (8-12Hz), beta (13-30Hz), and gamma (from 30Hz and up to 50Hz) band). All signals underwent common average referencing for noise filtering and followed the analysis procedure described in section 3.2.3.

3.4. Experiment Procedure

Taken together, following methodology was employed. The participants completed online surveys on the day before EEG recording. EEG recording consisted of two sessions with three minutes break in between sessions, after one minute dump (device stabilization) and one minute referencing. Each session comprised of fifty trials, and each trial was a series of cross fixation – image presentation – rest – and optional rest, depending on the state of participant. After the EEG recording, participants rated fifty images through paper-and-pencil survey. Figure 10 is a diagram that shows whole picture of this experiment.

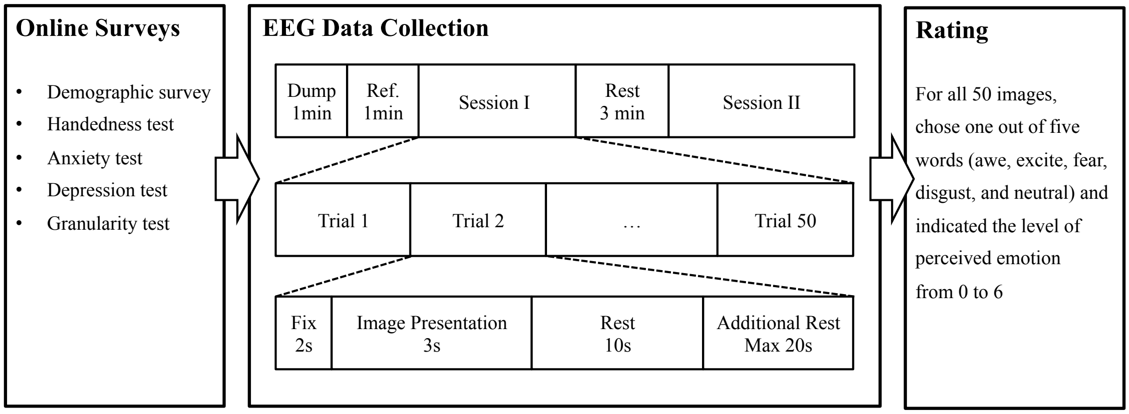


Figure 10 Experiment procedure

3.5. Statistical Analyses

Following analysis methods were employed to test the hypotheses described in section 2.6:

- Normality test was used to test whether the distribution of ERP amplitude and latency meet the normality assumption of the analysis of variance (ANOVA). If the data was not normally distributed and not proper for ANOVA, Nonparametric Wilcoxon Test (Mann-Whitney U-statistics) was applied.
- ANOVA was done for Hypothesis 1 and 2 with three parameters: GRAN (granularity; 2 levels; high and low), CHAN (channel; 16 levels; 1 to 16), and EMOT (emotion; 5 levels; awe, excite, fear, disgust, and neutral). Hypothesis 1 paid attention to the interaction effect EMOT*CHAN, and Hypothesis 2 focused on the main effect EMOT.
- Tukey's HSD test was used for post-hoc analysis, because it has greater power than the other tests and can maintain the Type I error at the same time (Jaccard, Becker, & Wood, 1984). It found the significant difference between each level of the independent variables.
- Regression was done for Hypothesis 3A, 3B and 4, in order to appreciate the continuous nature of granularity. In hypothesis 3, changes of ERP components

by granularity value were measured. In hypothesis 4, difference of coherence change by granularity value was measured.

4. RESULTS

4.1. Results of Hypotheses

ERP amplitudes were the maximum positive or minimum negative peaks at six different intervals: N1 (160-240 ms), P2 (200-260 ms), N2 (260-300 ms), P3 (300-360 ms), N4 (360-450 ms), and LPP (450-550 ms) in microvolt unit (μV; 10^{-6} V). Peaks before 300 ms (i.e., N1, P2, N2) were considered to be 'early' components and the peaks after 300 ms (N4, LPP) were considered to be 'late' components. ERP latencies were defined as the timing of the peaks appeared. The intervals were determined based on visual inspection and previous studies. EPN magnitude was calculated by subtracting N2 amplitude from P2, in terms of amplitude at posterior electrode sites (P3/4/7/8). Figure 11 depicts each component on the ERP waveform extracted from this experiment. For a simpler representation, the waveform was collapsed over positive and negative emotions.

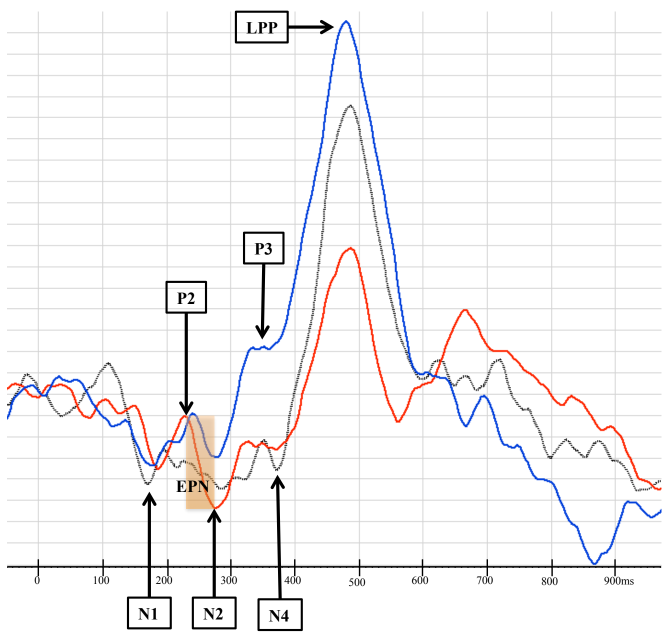
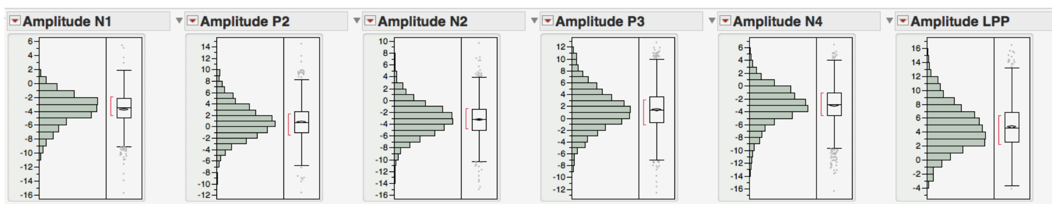


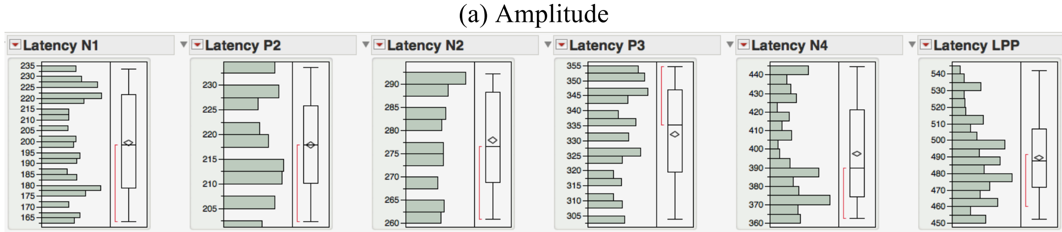
Figure 11 ERP components with three emotion categories (blue: ERP waveform collapsed over positive, red: collapsed over negative emotions, black dashed: neutral).

4.1.1. Normality Test

Normality test was used to verify if the latency and amplitude of each ERP components (N1, P2, N2, EPN, P3, N4, LPP) follow normal distribution. Goodness-of-fit test (Shapiro-Wilk W Test) was used for all 14 cases, and the null hypothesis (the data is from the normal distribution) was rejected with $p < .0001$ in all cases, meaning that the data sets are non-normal distribution. When visually inspected, the latencies were almost uniformly distributed, while the distributions of amplitudes were bell-shaped. Figure 12 shows how the distribution looked like.



(a) Amplitude



(b) Latency

Figure 12 Distribution of latencies and amplitudes of each ERP components

If the data is not normally distributed, the chance of false positive increases, because ANOVA assumes normal distribution of measurement variable. Nevertheless, ANOVA is not very sensitive to moderate deviation from normality (Glass, Peckham, & Sanders, 1972; Harwell, Rubinstein, Hayes, & Olds, 1992). This is due to central limit theorem; the distribution of the means of large number of random samples converges to normal. As the visual distribution of amplitudes resembles normal distribution, we decided to adapt ANOVA for amplitude measurement. However, for the latency, we decided to use nonparametric test, Wilcoxon test. Table 11 shows what analysis method was used for each combination of independent (row) and dependent (column) variables.

Table 11 Statistical analyses

	ERP Amplitude	ERP Latency	Coherence
Discrete Emotion	ANOVA (Hypothesis 1, 2)	Wilcoxon Test (Hypothesis 2)	-
Channel		-	-
Granularity (group)		Wilcoxon Test (Hypothesis 3)	Student's *t*-test (Hypothesis 4)
Granularity (value)	Regression (Hypothesis 3)	-	Regression (Hypothesis 4)

4.1.2. ANOVA and Wilcoxon Test for Hypothesis 1 and 2

When ANOVA was done with three parameters (GRAN, CHAN, EMOT), GRAN group was divided based on the grand mean 0.803, and each group had average granularity 0.718 and 0.888. When the amplitudes of each of six components were fitted by the full factorial model of three main effects above, all three main effects and interaction effect of GRAN*EMOT were significant in almost all six components. See the Table 12 below for *F*-values and *p*-values.

Table 12 ANOVA: effect tests (average values and p-values)

ERP Components	Effects	*F*-value	*p*-value
N1 (M = -3.76, SD = 2.26)	GRAN	$F(1,1440) = 0.0061$	0.9369
	EMOT	$F(4,1440) = 8.7676$	< .0001*
	CHAN	$F(15,1440) = 15.2467$	< .0001*
	GRAN*EMOT	$F(4,1440) = 12.8382$	< .0001*
	GRAN*CHAN	$F(15,1440) = 0.1835$	0.9998
	EMOT*CHAN	$F(60,1440) = 0.4326$	0.9999
	GRAN*EMOT*CHAN	$F(60,1440) = 0.2948$	1.0000
P2 (M = 0.83, SD = 2.99)	GRAN	13.7756	0.0004*
	EMOT	4.1067	0.0007*
	CHAN	22.5723	< .0001*
	GRAN*EMOT	8.9504	< .0001*

Table 12 continued

	GRAN*CHAN	0.8886	0.9022
	EMOT*CHAN	0.4380	1.0000
	GRAN*EMOT*CHAN	0.3901	1.0000
N2 (M = -3.18, SD = 2.84)	GRAN	13.7756	0.0001*
	EMOT	4.1067	0.0023*
	CHAN	22.5723	< .0001*
	GRAN*EMOT	8.9504	< .0001*
	GRAN*CHAN	0.8886	0.5743
	EMOT*CHAN	0.4380	1.0000
	GRAN*EMOT*CHAN	0.3901	1.0000
EPN (M = 4.74, SD = 3.48)	GRAN	44.7516	< .0001*
	EMOT	5.7262	0.0001*
	CHAN	5.5587	< .0001*
	GRAN*EMOT	1.3804	0.2384
	GRAN*CHAN	0.3599	0.9880
	EMOT*CHAN	0.7533	0.9189
	GRAN*EMOT*CHAN	0.2929	1.0000
P3 (M = 1.43, SD = 3.49)	GRAN	12.5295	0.0006*
	EMOT	17.5462	< .0001*
	CHAN	12.4065	.0001*
	GRAN*EMOT	6.8472	< .0001*
	GRAN*CHAN	0.2420	0.9992
	EMOT*CHAN	0.7690	0.9086
	GRAN*EMOT*CHAN	0.3156	1.0000
N4 (M = -2.99, SD = 2.95)	GRAN	10.0056	0.0016*
	EMOT	60.8155	< .0001*
	CHAN	4.6690	< .0001*
	GRAN*EMOT	4.8680	0.0007*
	GRAN*CHAN	0.7432	0.7416
	EMOT*CHAN	0.5172	0.9992
	GRAN*EMOT*CHAN	0.2360	1.0000
LPP (M = 4.79, SD = 3.28)	GRAN	49.4773	< .0001*
	EMOT	82.6736	< .0001*
	CHAN	13.9443	< .0001*
	GRAN*EMOT	4.4381	0.0014*
	GRAN*CHAN	1.0050	0.4468
	EMOT*CHAN	0.4043	1.0000
	GRAN*EMOT*CHAN	0.2587	1.0000

4.1.2.1. Hypothesis 1 – No Interaction Between Emotion and Channel

Hypothesis 1 was accepted. As shown in Table 12, the interaction between emotion and channel (EMOT*CHAN) was not found in any components, meaning that discrete emotions were processed in similar locations.

4.1.2.2. Hypothesis 2 – Different ERPs in Discrete Emotions

Hypothesis 2 was accepted. EMOT effect was significant in ERP amplitudes in the ANOVA test. However, since GRAN*EMOT interaction effect was observed, different ANOVA model was fitted for the Hypothesis 2. EMOT was treated as a single factor and two different one-way ANOVAs: one with high granular people only, and the other with low granular people only. The criterion of dividing the group was 0.805 (median).

Emotion effect was significant in all components (p<.0001 for all and p=0.0061 for high granularity group's N1), except for high granularity group's P2 component (p=0.0858), low granularity group's N2 component (p=0.2935), and ERP component in low group (p=0.8228). Graphs in Figure 13 show how two groups' reaction sometimes differed in each emotion. Y-axis is ERP amplitude of each component, and x-axis represents five emotions within each granularity group. Tukey-Kramer post-hoc analyses showed that there are emotion sets that are significantly different from each other. Levels not connected by same letter are significantly different. The amplitude was averaged over channels.

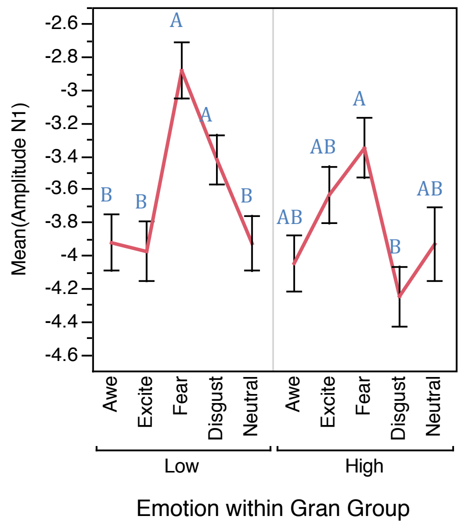


Figure 13 (a) Effect of discrete emotions on N1 component in low and high granular group

In N1, low group's reaction to fear was high in amplitude (small negativity) compared to excite ($p<.0001$), neutral ($p=0.0001$), and awe ($p=0.0001$), but not disgust. High group's reaction to fear was distinct from disgust ($p=0.0060$) only.

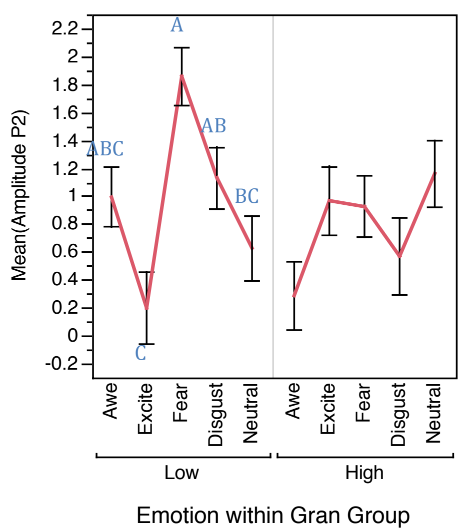


Figure 13 (b) Effect of discrete emotions on P2 component in high and low granularity group

In P2, low group showed high amplitude to fear compared to neutral (*p*=0.0012) and excite (*p*<.0001), but not disgust or awe. Excite was significantly lower than disgust (*p*=0.0295) as well as fear, but not awe or neutral. Emotion effect was not significant in high group (*p*=0.0858).

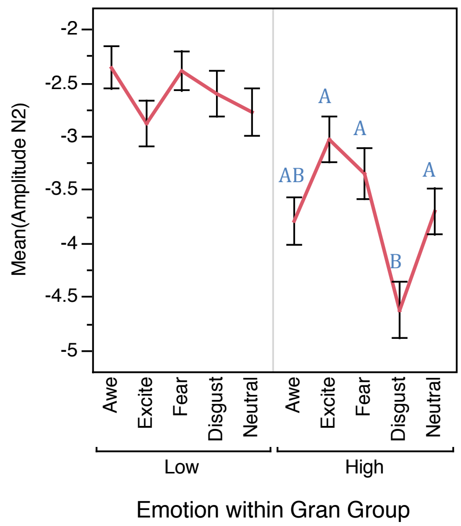


Figure 13 (c) Effect of discrete emotions on N2 component in high and low granularity group

In N2, low group did not exhibit emotion effect (*p*=0.2935). High group showed low disgust (more negativity to disgust) than excite (*p*<.0001), fear (*p*=0.0009), and neutral (*p*=0.0369), but not awe.

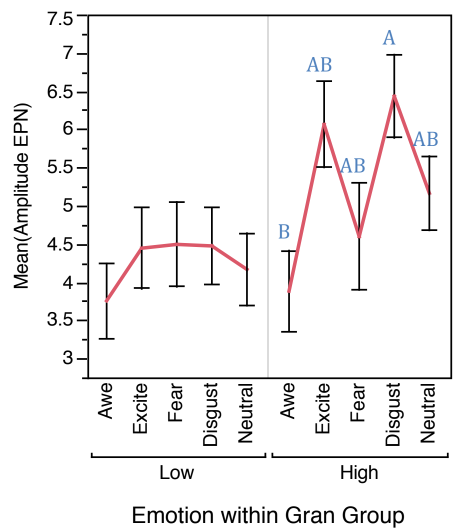


Figure 13 (d) Effect of discrete emotions on EPN component in high and low granularity group

The magnitude of EPN in was not affected by discrete emotions in low group (p=0.8228). However in high group, EPN was influenced by discrete emotions (p=0.0108), especially between disgust and awe (p=0.0510).

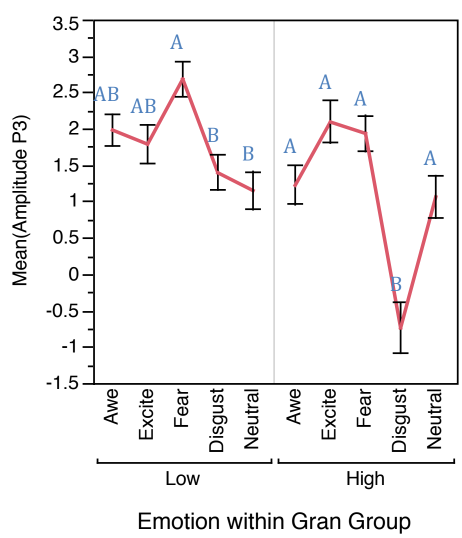


Figure 13 (e) Effect of discrete emotions on P3 component in high and low granularity group

In P3, low group showed higher fear amplitude to disgust (p=0.0019) and neutral (p<.0001), but it was not significantly different from excite or awe. On the other hand, high group showed significantly smaller peak to disgust compared to excite, fear, awe, and neutral (p<.0001).

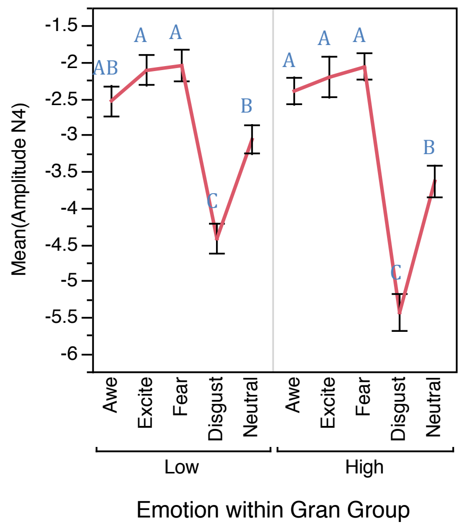


Figure 13 (f) Effect of discrete emotions on N4 component in high and low granularity group

In N4, both groups showed significantly low disgust peak compared to all other emotions: awe, excite, fear and neutral (p<.0001). Also, neutral was lower than fear (p=0.0046) and excite (p=0.0100) in low group. In addition, neutral was lower than fear (p<.0001), excite (p<.0001) as well as awe (p=0.0011) in high group.

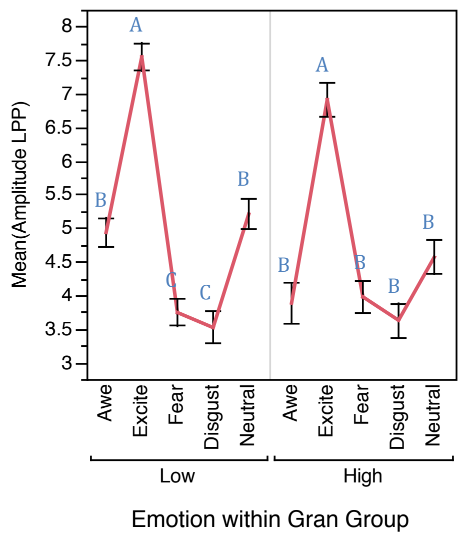


Figure 13 (g) Effect of discrete emotions on LPP component in high and low granularity group

LPP amplitude was significantly high for excite category than all other emotion categories in low group (p<.0001). Furthermore, low group's awe was higher than fear (p=0.0011) and disgust (p<.0001). Neutral was also higher and disgust and fear (p<.0001). The pattern was similar in high group. Excite was higher than all other emotions (p<.0001). However, there were no other significantly different pairs.

Emotion effect on latency was identified by the Wilcoxon test. The emotion effect on latency was significant in P2 component ($\chi^2(4)$=15.0549, p=0.0049). In Wilcoxon pairwise comparison, fear showed slower latency compared to all other emotions (vs. neutral p=0.0007, vs. disgust p=0.0049, vs. awe p=0.0169, vs. excite p=0.0487).

Latencies of all later components were affected by discrete emptions: P3 ($\chi^2(4)$=17.7911, p=0.0014), N4 ($\chi^2(4)$=23.0040, p=0.0001), LPP ($\chi^2(4)$=17.6833, p=0.0014). In P3, disgust showed faster reaction compared to awe (p=0.0003), neutral (p=0.0006), and fear (p=0.0130), but slower than excite (p=0.0213). In N4, fear was slower than excite (p<.0001), neutral (p=0.0003), disgust (p=0.0040), and awe (p=0.0139). Excite was faster than awe (p=0.0356). In LPP, fear was faster than disgust (p=0.0001) or neutral (p=0.0051). Disgust was also slower than awe (p=0.0058) or excite (p=0.0378).

4.1.3. Regression and Wilcoxon Test for Hypothesis 3

In order to see if the effect of granularity exists on emotional process, regression model was fitted for ERP components. To appreciate the continuous distribution of granularity, regression was used instead of ANOVA used in hypothesis 1 and 2. (Dividing participants into high and low granular group based on median may not correctly reflect the effect of granularity.) Shown below in Table 13 are linear regression results for each emotion with granularity as independent variable and ERP amplitudes as dependent variables. The model was fitted separately for each emotion in order to avoid distortion due to the interaction effect of granularity and emotion.

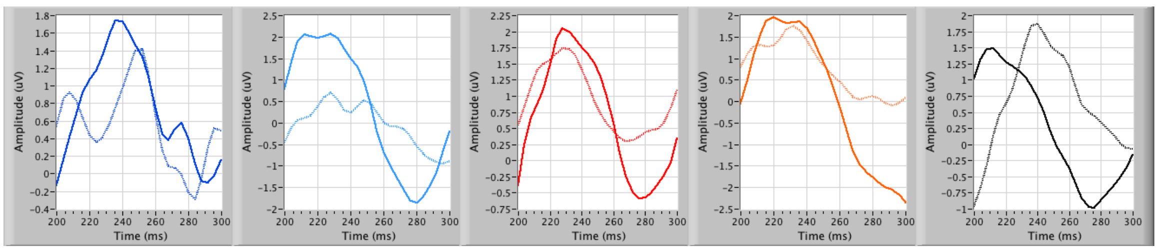
Table 13 Effect of granularity on ERP amplitudes in each discrete emotion

	Awe		Excite		Fear		Disgust		Neutral	
	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value
N1	-2.05	0.0665	4.72	<.0001*	-2.00	0.0870	-4.38	<.0001*	3.91	0.0027*
P2	-0.81	0.5983	8.95	<.0001*	-1.02	0.4778	-1.52	0.3603	5.76	0.0002*
N2	-2.72	0.0583	2.89	0.0419*	-4.58	0.0014*	-7.50	<.0001*	0.52	0.7240
EPN	1.91	0.1779	6.06	0.0002*	3.56	0.0331*	5.98	<.0001*	5.23	0.0002*
P3	1.65	0.3140	8.36	<.0001*	0.75	0.6481	-3.13	0.1290	6.13	0.0008*
N4	1.42	0.2784	5.79	0.0004*	1.64	0.2134	-2.67	0.0836	4.07	0.0003*
LPP	-7.24	<.0001*	1.50	0.0002*	-0.24	0.8689	-2.77	0.0878	-7.75	<.0001*

4.1.3.1. Hypothesis 3A – No Granularity Effect On Early ERPs

Hypothesis 3A was rejected. As shown in Table 13, granularity affected early ERP components. Granularity affected the earliest component N1 while processing disgust, excite and neutral. High granular people showed more negativity to disgust stimuli (β=-4.38, p<.0001), and less negativity to excite (β=4.72, p<.0001) and neutral stimuli (β=3.91, p=0.0027). Wilcoxon test showed that the high granular people were faster in N1 reaction (t(1332)=-2,76, p=0.0058). P2 was also influenced by granularity when processing excite (β=8.95, p<.0001) and neutral (β=5.76, p=0.0002). High granular people's N2 was larger for negative stimuli (fear β=-4.58, p=0.0014, and disgust β=-7.50, p<.0001), while smaller for excite (β=2.89, p=0.0419).

The magnitude of EPN was also significantly greater in high gran individuals when processing excite (β=6.06, p=0.0002), fear (β=3.56, p=0.0331), disgust (β=5.98, p=0.0001), and neutral (β=5.23, p=0.0002) stimuli. Figure 14 shows the average waveform of posterior channels P3 and P4, between 200ms-300ms interval. Solid line is an average of 10 high granular participants, and dashed line is an average of 10 low granular participants. The positive peak around 220ms is P2 component, and the negative peak around 280ms is N2 component. The difference between two components (EPN) is generally larger in high granular group (solid line).



(a) Awe (b) Excite (c) Fear (d) Disgust (e) Neutral

Figure 14 P2, N2 and EPN of two granularity groups (solid: high granularity, dashed: low granularity)

4.1.3.2. Hypothesis 3B – Granularity Effect on Late ERPs

Hypothesis 3B was also rejected. It was predicted that more granularity would lead to greater negativity of N4 and greater positivity of LPP. However, being inconsistent with the prediction, the magnitude of peak decreased in N4 and LPP as granularity increases. As shown in Table 13, this effect was mostly significant in excite (N4 β=5.79, p=0.0004, LPP β=1.50, p=0.0002) and neutral stimuli (N4 β=4.07, p=0.0003, LPP β=-7.75, p<.0001). Awe processing was affected for the first time in LPP stage (β=-7.24, p<.0001). In terms of latency tested by nonparametric Wilcoxon, high granular people were significantly slower at late components: P3 (t(1332)=5.15, p<.0001), N4 (t(1332)=9.18, p<.0001), and LPP (t(1332)=2.31, p=0.0210).

4.1.4. Regression for Hypothesis 4

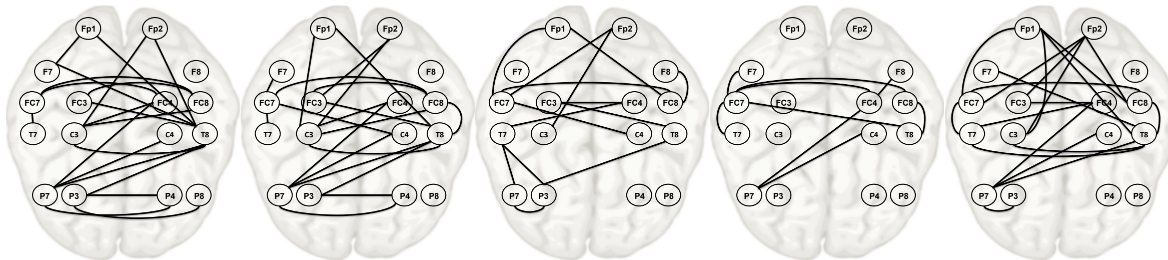
4.1.4.1. Hypothesis 4 – Granularity Effect on Coherence

When coherence of 1 second after the stimulus onset was compared with the coherence of 1 second before the stimulus onset, significant reduction was observed in most of the pairs of brain sites. Table 14 summarizes the number of electrode pairs that showed decreased or increased coherence in high and low granular group. Reduction happened commonly across all frequency bands, while the increment of coherence was rarely observed only in low granular group. In theta, beta and gamma band, high granular people had more number of channel pairs showing reduced coherence values, compared to low granular people.

Table 14 The number of electrode pairs that showed decreased/increased coherence in each granularity group (α=0.01)

	Theta (4-7Hz)				Alpha (8-12Hz)				Beta (13-30Hz)				Gamma (30-50Hz)			
	Decrease		Increase		Decrease		Increase		Decrease		Increase		Decrease		Increase	
Gran.	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Awe	43	35	0	2	29	37	0	6	29	23	0	3	55	35	0	6
Excite	27	28	0	2	33	38	0	7	26	23	0	6	53	26	0	7
Fear	37	31	0	2	30	40	0	4	30	23	0	5	36	29	0	4
Disgust	39	34	0	2	31	46	0	4	33	18	0	6	59	27	0	1
Neutral	45	31	0	2	28	34	1	5	20	19	0	6	43	27	0	4

Our interest was in beta band, since it is capable of long-range signaling. Figure 15 compares the reduced coherence value of high granular group and low granular group in beta band. Black solid lines indicate that high granular people's coherence reduction was significantly greater than low granular people's coherence. The number was smaller in negative stimuli presentation (fear and disgust). No channel pair showed greater coherence reduction in low granular group. See Appendix I for comparison in all other frequency bands.



(a) Awe (20 pairs) (b) Excite (20 pairs) (c) Fear (14 pairs) (d) Disgust (9 pairs) (e) Neutral (20 pairs)

Figure 15 The number of coherence reduction between high and low granularity group in beta band (α=0.01)

Beta band change was further analyzed to study functional coupling of prefrontal and parietal area. Effect of granularity on prefrontal-parietal coherence each hemisphere was tested with regression as described in section 3.2.3.4. The result showed that individual differences in granularity predicted to which extent coherence decreased during the emotional provocation. In individuals high in granularity, the co-activation of prefrontal area and posterior areas decreased to a greater extent, especially in left hemisphere (β=-0.356, p=0.036) during the first 1 second of image presentation (right hemisphere β=-0.120, p=0.469). Figure 16 shows the trend of reduction.

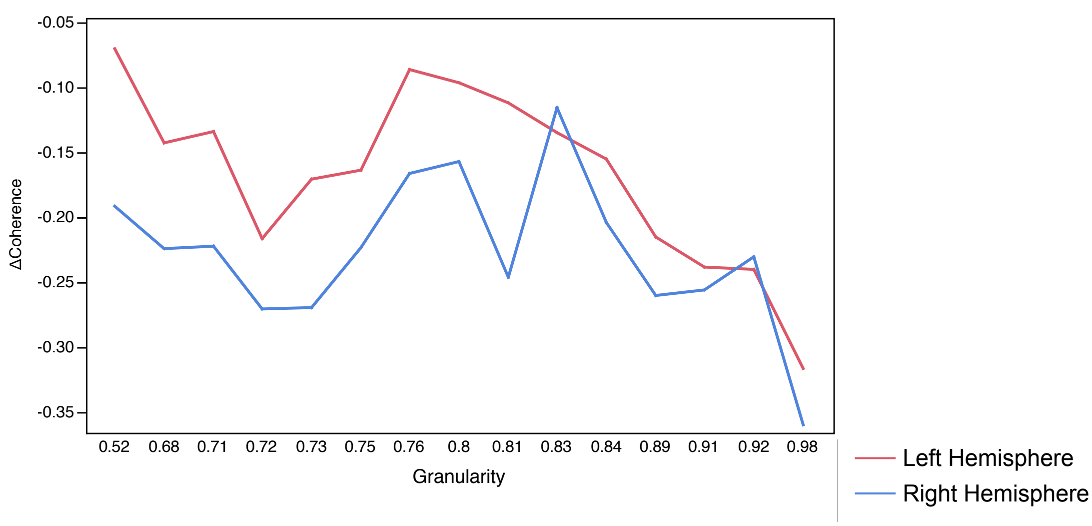


Figure 16 Granularity effect on prefrontal-posterior coherence reduction, collapsed over emotions

5. DISCUSSION AND IMPLICATIONS

5.1. Discussion of Research Questions and Hypotheses

5.1.1. Research Question 1

Research question 1 was about the emotion model. First, it was hypothesized that there would be no interaction effect between emotions and brain areas, because each of discrete emotions might follow similar processing of core affect generation, situated conceptualization, and emotional representation, according to the constructionist model. That means at least activation of brain area is not dependent on discrete emotions. As there was no interaction effect found, the constructionist model was partially supported through the experiment. However, the caveat of this experiment is that we only measured activation of lateral cortical areas. Subcortical or med-cortical area might have differed.

Hypothesis 2 asked if discrete emotions draw different amount of neural resource and where the difference starts. The result showed there are some emotions that differ from each other from the early ERP components. First, ERP reaction to fear contrasted with other emotions showing smaller negativity at N1 (higher amplitude). This may be due to the sustained positive amplitude produced earlier than N1, such as P1 (see Oloffson et al., 2008). When visually inspect ERP waveform, fear waveform was above the other emotions' waveforms, starting around 100ms, with N1 peak of fear being above other emotions. This is consistent with previous research that argued uncertainty of negative feature lead to favorable processing of negative stimulus (e.g., Bradley, 2010; Codispoti et al., 2006; Eimer et al., 2003). Threatening feature of fearful images might have caused more activation of brain cortex and marked higher amplitudes. The high amplitude of fear stimuli, especially in low granularity group, lasted until P3 component. There is no previous literature about granularity effect on threatening stimulus processing, but long lasting brain activation to fearful stimulus could indicate that low granular people take longer time to process threatening stimulus.

A conspicuous reaction to disgust started later, at N2 component, first by high granularity group. Such low amplitude was maintained until N4 component in high group.

Low granularity group showed large negativity only in N4. Higher negativity of N4 in both groups could imply that disgust require more cognitive effort in make meaning of interoceptive sensations caused by disgusting stimuli. High granular people might have been more sensitive and rapid in perceiving the visceral affect and show earlier negative waveform. Or possibly because the high complexity of disgusting stimuli might have required more access to concept knowledge to make meaning, generating greater negative peaks.

Two groups showed similar reaction pattern to discrete emotions after N4. In particular, excite category exhibited faster and the highest LPP peak. It might be due to the intensive excitement of brain circuits, caused by metabolic mobilization caused by exciting stimuli. Many of these stimuli depicted people engaging in action, so it could evoke a person's simulation of actions while viewing stimuli (e.g., Dapretto et al., 2006). The high LPP amplitude seemed independent from the level of arousal, since fear category was higher in arousal than excite category but showed smaller LPP peak.

Some result might be due to the varied saliency of visual features. For example, images in fear and excite category were similar in complexity and dynamicity (refer to Figure 7) and their ERP amplitudes were not significantly different from each other, except for LPP and low granular people's early components (N1 and P2, refer to Figure 13). Also, disgusting images were more complex than other images and showed more negative middle ERPs. These suggest the possibility of ERP components impacted by visual features, not by emotional features. However, neutral images low in both complexity and dynamicity did not show prominent peaks different from other emotions. If visual features were the main effects that altered ERP reaction, neutral images might have showed noticeable difference, in that they were simpler and more static compared to other images. In addition, the linear regression of ERP components' amplitudes by complexity and dynamicity showed very low R^2 values ($R^2<0.12$), meaning that there is no direct linear relationship between the visual features and ERP components.

In order to support the constructionist model and reject the locationist model, the ERP components should not show consistent and specific difference between discrete emotions, at least during generating core affect. In other words, specific emotions would not be differentiable as ERP changes in early stages where core affect is formed. According to the previous experiments, emotion effect was not found in very early time interval, before N1 component; it might imply that core affect is formed very early, even before N1. In fact, when averaged over channels, positive peak between 50ms and 100ms was not affected by discrete emotions ($F(4)=0.6787$, $p=0.6084$). If core affects are shaped within this time frame, this might support constructionist model and reject locationist model. Figure 17 shows the revised model for future experiment, mapping more early components to core affect and other components related to attention and memory to conceptualization.

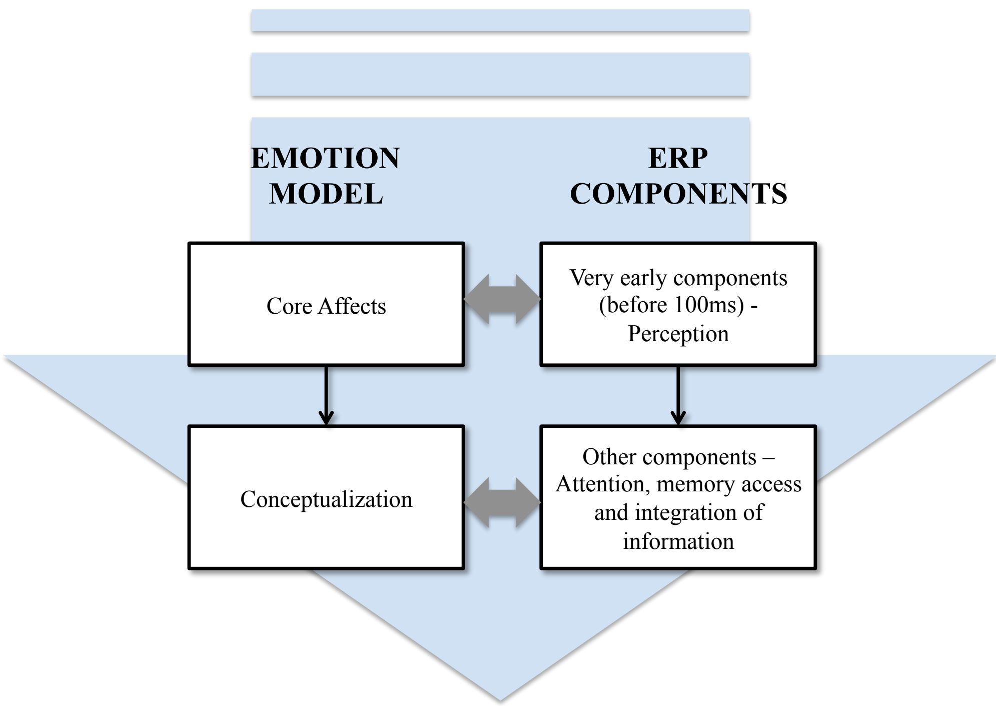


Figure 17 Revised mapping of constructionist model on ERP components

In other case, P2 component in posterior area could also represent the formation of core affects through amygdala projections to visual cortex (Amaral, Price, Pitkanen, &

Carmichael, 1992), because similar amplitudes were observed across all discrete emotions. The graph is drawn in Figure 18.

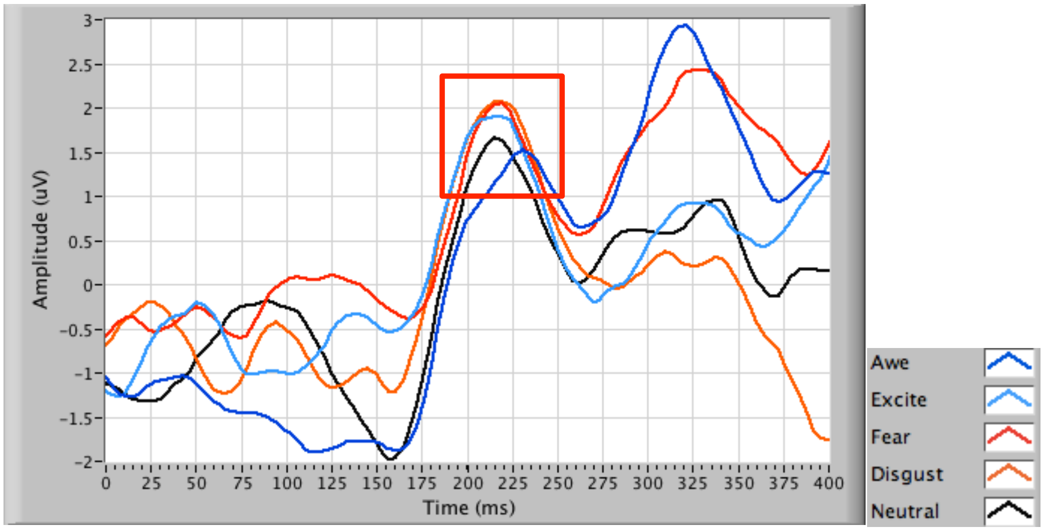


Figure 18 ERP waveform between 0-400ms in parietal area, collapsed over P3/4/7/8. See Appendix G for the results of each channel

Since the results lead to various interpretations, this experiment could not conclusively support any emotion models. In order to support constructionist model in particular, closer investigation is needed to reveal when is the actual time interval for core affect and conceptualization.

5.1.2. Research Question 2

Research question 2 was about the effect of individual difference in granularity. In the previous research question, participants were into high and low granular group, and it might not properly reflect the effect of granularity. Thus, linear regression was used to test hypothesis 3 and 4, using continuous granularity values. First, the result rejected both Hypothesis 3A and 3B, because higher granular people tended to show more cortical activation in the early stage and less activation in the later stage. It suggested that granularity influences neural processing from the very beginning stage of perception.

Granularity effect was observed in most of the ERP components. Especially, early selective attention represented by EPN was large in highly granular individuals. It is possible that high granular people initially allocated more cognitive resource and paid more attention to the stimulus at the early phases and constructed solid core affects. As a consequence, early attention might play an important role in forming representations of emotion, and this emotional experience might affect later emotional process as a complex conceptual knowledge about affective states. It is also probable that greater EPN reflected greater conceptualization as well as core affect, because greater EPN means that high granular people were collecting more information from the stimuli. If this experiment has to be done again, even earlier activity (before N1) for high gran individuals would worth investigating, since conceptualization can occur within 100ms.

On the other hand, we observed that negativity of N4 was smaller and the positivity of LPP was also smaller and latencies were slow in high granularity individuals, rejecting Hypothesis 3B. As these components are related to conceptualization (e.g., accessing previous knowledge and creating semantic meaning), weaker intensity of N4 and LPP may not make sense from 'enhanced perception hypothesis' point of view of many studies, which argues that high LPP indicates temporary increase in attention to facilitate the processing of the affective stimulus. However, it could be related to efficiency of affective processing. Perhaps individuals low in granularity are trying harder to make meaning of stimulus so have greater N4 and LPP, compared to high granular individuals who process routine conceptualization.

Another interesting result is delayed latency of P3 and N4. This could be because of continuous iterative feedback between functional areas related to emotional process (e.g., visual, affective, and conceptual) as the high granularity people process the stimuli. However, the total amount of brain resource allocated to the iterative process could not be measured in the current study. It requires further development of new analysis methods, such as mean ERP amplitude suggested by Luck (2005); mean amplitude over a fairly broad time interval could be superior to measurements of peak amplitude. Maybe high granular people were processing more in this later stage.

Hypothesis 4 intended to see if the granularity impacts coherence of brain areas. Overall, reduced coherence values (as shown in Table 14) suggested reduced functional coupling of neurons. In general, high granular people showed more reduction in coherence. This might indicate that low granular people's brain works harder to conceptualize; they need connection between brain areas. Or high granular people might have habitual connection and they need more reduction to reach a certain level of decoupling for information processing. This account can also explain low N4 and LPP amplitude of high granular people.

Significantly decreased beta activity was observed in in high granular group, and it was consistent with previous research. Reduced coupling indexed lessened power of signaling status quo (suggested by Engel and Fries, 2010), meaning acceptance of new status. Since bottom-up process triggered by perceptual input plays more roles in emotional process than top-down executive control (Decety & Moriguchi, 2007), the result implied that the higher granular people accepted the emotional features without overriding them with top-down influences, showing flexible cognitive control. Similarly, Reiser et al. (2012) revealed that people could sympathize well (high score in "trait absorption") showed decreased beta coherence when viewing emotional stimuli, due to the loosened cognitive regulation and consequent greater emotional impact. Similar result of high granularity and high trait absorption is also consistent with idea that highly granular people are more "emotionally intelligent". In addition, it is in line with the ERP results where EPN was bigger in high granular people; they might be more dependent on external cues.

5.2. Findings

5.2.1. Discrete Emotions and Implications for Constructionist Model

The results showed that discrete emotions sometimes exhibit different amplitudes and latencies after about 150ms. For instance, although both awe and excite were in positive emotion category, they showed significantly different ERP responses. One might argue that higher LPP of excite category is due to the arousal difference between two emotions as described in previous studies. However, excite emotion evoked even greater LPP compared to negative emotions that were scored higher in arousal dimension. Likewise, fear and disgust showed different patterns. Fear category showed intensive early components, while disgust reaction was strong in later components. Although both fear and disgust protects the body from dangerous situations by evaluating whether inputs have a potential threat, the source factors of two emotions are different. It might have caused the difference. Taken together, the results imply that a vague bundle of ‘positive emotion’ of ‘negative emotion’ can exhibit very different pattern, depending on how it is constituted. Distinctive pattern of each discrete emotion will help identifying the dynamics of more basic psychological processes. Also, it suggests that core affect might happen well before 100ms, showing no difference between discrete emotions.

5.2.2. Granularity is Influenced by Early Perception

Emotional granularity has been explained as the difference in the ability of using previous conceptual knowledge for categorization and conceptualization of current situation (Lindquist, 2008). According to the present results, highly granular people showed different reaction not only in the late states, but also in early states, which is related to unintentional brain resource allocation to perceptual features. It might mean that the tendency to conceptualize affective state into more discrete emotion is not about conceptualization itself, but also about early alignment of core affect directed by attention. In addition, the reduction of beta band coherence indicates that high granularity could be associated with dependency to external cues, deeper emotional involvement to the cues, and reduced executive control. It implies that early attentional feature of emotional stimulus could influence the experience of emotion. For example, stronger attention would give rise to more distinctive and salient emotional experience. It is also possible that the whole process accumulates as conceptual knowledge about affective state and influence the conceptualization process in the future. Yet it needs more investigation. There might exist another personality that regulates early attention and is highly correlated to emotional granularity. In that case, the early attention is not a direct consequence of granularity. In addition, such allocation of attention might be the process of situated conceptualization, not the effect of core affect. If it is supported by further research, granularity can represent different ability of conceptualization.

5.3. Summary of Contributions

This study claims that understanding the process of discrete emotion is important, as the process of each emotion differed from each other. Also, individual difference in emotional granularity and its connection to early attention proposed a possible relationship between early attention and emotional experience. Applying these to other areas of study and developing on it will contribute in producing novel research outcomes. Potential research implications are listed in the Table 15.

Table 15 Human factors and ergonomics research implications related to the present study

Results	Application Area	Contributions	Reference
Distinct patterns of discrete emotions	Adaptive System for Safety	• Understanding reaction patterns of each discrete emotion can lead to developing more safe and reliable system, by providing appropriate feedbacks that promote rational decision-making and reduce human errors • System can assess the operator's emotional state in real-time and provide suitable warning or assistance to promote safe operation (e.g., driving, pilot)	(Causse et al., 2013; Zhang & Kaber, 2013)
	Efficient BCI	• Understanding each discrete emotion's ERP pattern can affect building more efficient brain-computer interface, an emotionally adaptive system that can identify user's emotional state and update embedded model, thereby enhance BCI operation	(Garcia–Molina, Tsoneva, & Nijholt, 2013)

Table 15 continued

High granular individuals' early attention to affective stimulus	Product/service Design	• Early attention was observed in those who can perceive emotion more precisely. It implies that early impression of design feature might determine perceived salience of an emotion. • In designing affective products or services, enhancing attentional value of feature would help successfully evoking intended emotions	(Chien & Lin, 2014; Horn & Salvendy, 2009; Kim & Moon, 1998; Merritt, 2011; Norman, 2004; Pelet et al., 2013)
	Healthcare	• Enhanced attention to emotional stimulus could increase the effect of priming • Through the priming of a certain discrete emotion, we can motivate healthier habit, help people to better cope with negative health information, or reduce perceived severity of symptoms	(Carver & Scheier, 2004; Harrison et al., 2010; Lin, Ramakrishnan, Chang, Spraragen, & Zhu, 2013; Raghunathan & Trope, 2002)

5.4. Limitations of Current Study and Recommendations for Future Research

First, the present study analyzed brain data from twenty participants. Although it was a controlled participant group in terms of gender, handedness, and mental state, the number is not sufficient to generalize to the entire population. Also, only male participants were recruited to the experiment, because gender effect is under debate. The results might be generalized to all populations, based on the fact that there is no general effect on emotion perception (Barrett et al., 1998). However, some researchers claimed that gender contributes a lot to the intensity of experienced emotions (Fujita, Diener, & Sandvik, 1991) and female might bring about different results. In some studies, females reacted more strongly and for a long duration to emotional stimulus (i.e., valence), whereas males react more to arousal level of stimulus (Lang et al., 1993). Thus, the present study needs bigger population to reduce variability.

Second, the experiment was conducted with limited number of electrodes on scalp (sixteen channels). Although each electrode was representative of each functional area of brain, it was not enough in terms of spatial sampling. Low electrode density might have caused noise in the data, due to the different resistivity of skull (Ryynanen, Hyttinen, Laarne, & Malmivuo, 2004; Ryynanen, Hyttinen, & Malmivuo, 2006). Moreover, with this number of electrodes, exact source localization was impossible. Using EEG with 16 channels, we could only get limited resolution and accuracy: low-resolution brain electromagnetic tomography (LORETA) method has 30% accuracy with 25 channels (Michel et al., 2004).

Third, we need to be careful in interpreting coherence results, because coherence does not necessarily indicate synchrony of rhythm. For example, inter-hemispheric coherence does always mean increased functional coupling between the oscillation generated in the left and right hemispheres (Florian, Andrew, & Pfurtscheller, 1998). Using different method that can consider frequency bands' activity such as event-related desynchronization or synchronization (ERD/ERS) method is suggested for higher temporal resolution for each frequency band. As measuring ERP assumes that the evoked activity has a more or less fixed time-delay to the stimulus, we can also assume that a resetting of the phases of the ongoing EEG signals happens for cognitive operations. Hans Berger (1930) found that particular events can block or desynchronize the ongoing oscillatory activity of a certain frequency band, known that desynchronization, or suppressed spectral power. It reflects changes in the activity of neurons that control frequency components of ongoing EEG (Pfurtscheller & Lopes da Silva, 1999). Desynchronization or suppression of wave induced by an incident is called ERD, and synchronization or activation is called ERS. The functional meaning of ERS is that the underlying cortical area is in idling state, whereas ERD means the area is activated. The ERD/ERS is highly frequency band-specific and it can be observed simultaneous on the scalp, in different locations or at different time frame (Pfurtscheller & Silva, 1999).

In addition, visual stimuli used in this experiment had uncontrolled information that was unnecessary to evoke emotional reaction, such as different brightness, spatial frequency (Delplanque, N'diaye, Scherer, & Grandjean, 2007), complexity (Bradley, Hamby, Löw, & Lang, 2007), or dynamicity (Proverbio, Riva, & Zani, 2009). The effect of color is controversial. Yoto, Katsuura, Iwanaga, & Shimomura (2007) suggested the effect of color, while Codispoti et al. (2012) argued that colors do not affect recognition of the emotional content. Well-controlled image sets are required for similar future experiments' clear result.

The passive-viewing condition of this experiment may have affected the participants' attitude toward the emotional features, compared to active discrimination tasks such as oddball tasks used in several studies (Delplanque, Silvert, Hot, Rigoulot, & Sequeira, 2006; Delplanque et al., 2007; Keil et al., 2002; Mini, Palomba, Angrilli, & Bravi, 1996; Schupp et al., 2000). This is related to the weakness of lab setting. In the real world, affective states are formed from various input cues over time. We should be aware that the gap exists between real world situations and such a simplified situation. Nevertheless, such approach has provided new theoretical results in this area and was able to avoid context-dependent results.

Lastly, we need to consider that "brain state does change with repetitions of the same experience" (Kagan, 2007). The present experiment had a small number of participants, with relatively small number of trials. Although we repeated sessions in order to gain clear data, assuming that noise follows normal distribution and converges to zero as signals are collapsed trials, habituation or priming might have affected the results. Habituation is an automatic process that is beyond awareness (McKoon & Ratcliff, 1980). As each stimulus is encountered in the first session, the memory of the images is formed recently and possesses higher probability of being accessed than other information. It may cause higher baseline states of brain activity. Repeated emotional stimulus from IAPS reduced the magnitude of ERP peaks, starting N2 (Ferrari, Bradley, Codispoti, & Lang, 2011). According to Codispoti, Ferrari & Bradley (2007), reaction times were significantly faster for emotionally arousing pictures when second exposed to the same picture. Even featural overlap among pictures could cause the similar result. Maybe high granular people were more habituated by the first presentation of a stimulus. It could result in the appearance of smaller magnitude of later ERP components related to meaning processing.

For the future work, it would be interesting to study factors that influence one's social experience, which forms the contents of knowledge and tendency of categorization (i.e., whether an affective state is emotional or not) (Barrett, 2006). Gender, ethnicity, age, social class, nationality, and religion are potential factors that can mute or enhance an emotional profile. In addition, there also exist interesting special cases, such as anxiety, depression, or attention deficit hyperactivity disorder (ADHD) that may be associated with a psychological filter that. It was reported that patients with high anxiety experience more negative emotion and that the gamma band can monitor fluctuations in pathological worry of the patients (Oathes et al., 2008). Depressed people also showed greater reaction to threatening cues and exhibited significantly larger startle reflexes than those without (Lang, Bradley, & Cuthbert, 1998). Other personality factors such as extraversion-introversion or neuroticism-stability can be an interesting variable that can help uncovering the neural process of emotion as well (Gale et al., 2001).

Combining EEG and fMRI studies will also provide more insights into the area of neuroergonomics. The combination of two has been used to identify the neural correlates of clinically or behaviorally important spontaneous EEG activity (Menon & Crottaz-Herbette, 2005). In this area, fMRI can lend support to the poor spatial resolution of EEG and help observed subcortical processes, and EEG can back up the poor temporal resolution of fMRI.

5.5. Conclusion

This study investigated the neural activation in response to discrete affective stimuli. The first finding was that discrete emotions exhibit distinctive patterns, supporting the constructionist approach to a limited extent. The results suggested that the formation of core affect could take place before 100ms. The second finding was that individuals who experience their affective state as a more discrete emotion were better in early spotting of emotional features and were relatively free from emotional regulations.

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APPENDIX

APPENDIX A – Glossary of Terms

Coherence: A measure that indicates correlation of two distant cortex areas

Constructionist approach (Psychological): "Emotion categories such as anger, sadness, fear, and so forth, are common sense categories whose instances emerge from the combination of more basic psychological operations that are the common ingredients of all mental states" (p.125) (Lindquist et al., 2012)

Core Affect: The most basic affective feelings and their neurophysiological counterparts that are consciously accessible (Russell & Barrett, 1999)

Emotion words: Emotion words are names of categories where similar abstract affective states are bond together.

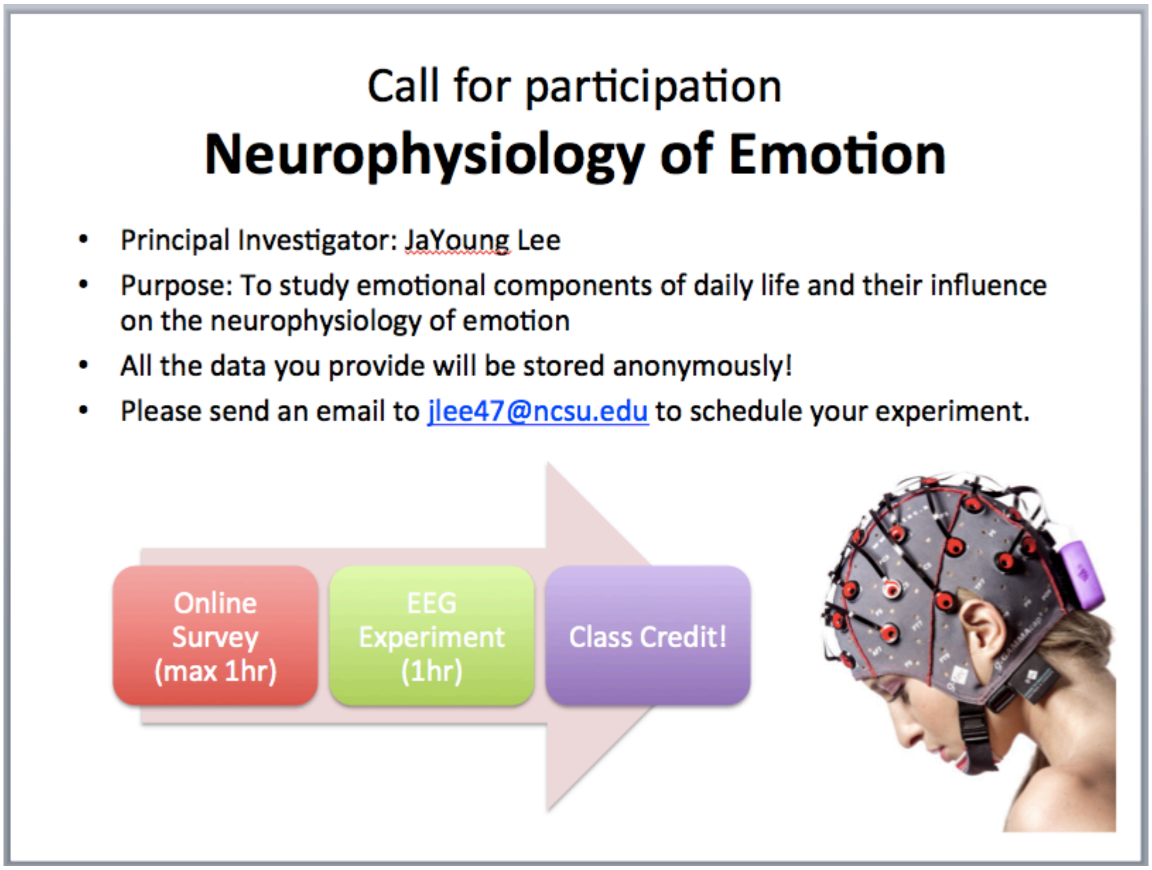
Emotional granularity: The tendency to represent emotional experience with precision and specificity (Tugade et al., 2004)

Locationist approach: Discrete emotion categories are specifically localized to discrete brain locations/networks (Lindquist et al., 2012)

Situated conceptualization: Situation-specific inferences of sensations from the body or external world. Prior experiences are activated by the present situation. (Barsalou 2003; Lindquist et al., 2012)

Two-factor theory of emotion: Schachter's model that emotion is consists of two factors: physiological arousal and cognitive label (Schachter & Singer 1962)

APPENDIX B – Recruitment Flyer



APPENDIX C – Informed Consent Form

North Carolina State University
INFORMED CONSENT FORM for RESEARCH
This consent form is valid October 1, 2013 through October 1, 2014

Title of Study: *Granularity Difference and Conception of Discrete Emotions*

Principal Investigator: Ja Young Lee, graduate research assistant
Faculty Sponsor: Chang S. Nam, Ph. D.

PURPOSE OF PROJECT: I understand that this project is conducted to investigate effect of granularity in the perception of emotion. I have been asked to participate because I am a student in the Department of Industrial and Systems Engineering or the Department of Psychology the North Carolina State University.

INFORMATION: I understand that I will be asked to write one online journal (using Daily Reconstruction Method) and asked to test handedness, anxiety, and depression. Also, Electroencephalogram (EEG) signals will be collected, which involves measuring the electrical activity of the brain via electrodes. I need to wear EEG cap during the experiment. I also understand that I will be watching 120 emotional pictures and need to respond naturally. I am aware that my involvement in this study will take approximately 120 minutes.

RISKS: The anxiety and depression test may reveal emotional states and this may cause embarrassment in some cases. The pictures during the experiment may also cause mild emotional discomfort. Collecting EEG signals involves the use of a conductive gel and there is a small possibility of skin irritation. I understand that there are no factors related to this project that would place participants at more than minimal risk. No long-term emotional repercussions are foreseeable.

BENEFITS: I am aware that if I have any questions, I can ask the principal researcher's phone number or her email address that is on the bottom of this piece of paper. I understand that the published findings of this study should have an important impact on emotion research.

CONFIDENTIALITY: At no time will my identity be revealed. My identity will be kept in strict confidence. Furthermore, I am aware that no information that identifies me in any way will be released without my separate written approval. All identifiable information will be protected to the limits allowed by law.

COMPENSATION: I am aware that I will receive extra credit points for my class.

FREEDOM TO WITHDRAW: I understand that I may refuse to participate in this study. Further, I understand that agreement to participate may be withdrawn at any time without any penalty or loss of services that I am entitled to. I will still receive a class credit even if I withdraw prior to completion of the study.

APPROVAL: This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at the North Carolina State University.

PARTICIPANT'S RESPONSIBILITIES: Since we are going to have other students here, we don't want them to know everything that happened in the experiment today. So, please do not share what you did in this study to anyone.

What if you have questions about this study? If you have questions at any time about the project or the procedures, you may contact the principal investigator, Ja Young Lee at (678) 896-3011 or jlee47@ncsu.edu.

What if you have questions about your rights as a research participant? If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

QUESTIONS: Do you have any questions? Do you understand what I have said?

PARTICIPANT'S PERMISSION: I understand what has been explained to me and agree to participate.

Name (Please print): ____

______________________________ ______________ ____________
Signature Student ID Date

APPENDIX D – Online Survey

Thank you so much for participating in this survey! This study is a part of a study that explores perceptual processes under human emotion. The participation will take up to 30 minutes. At the end of this survey, you will move on to the next survey, which will take up to 30min. There is no anticipated direct benefit to you as a volunteer participant, except for class credits. However, this research will contribute to the body of knowledge on individual variations in emotional perception and further the understanding of the process of emotional perception. The information in the study records will be anonymous and kept strictly confidential. Given these steps, your responses will not link your name to any oral or written report of the study. If you have any questions related to this study, you may contact any of the following researcher: Ja Young Lee (jlee47@ncsu.edu) If you agree, please click ">>" button to begin.

Please specify your name or nickname here ______

Are you Male or Female?
- ❍ Male (1)
- ❍ Female (2)

What is your age? ______

HAND Please indicate your preference in using your left or right hand in the following tasks. Where the preference is so strong you would never use the other hand, unless absolutely forced to, put a check under 'strong left/right'. If you are indifferent, put one check in each column. Some of the activities require both hands. In these cases, the part of the task or object for which hand preference is wanted is indicated in parentheses.

	Left (1)	Strong Left (2)	Right (3)	Strong Right (4)
Writing (1)	❍	❍	❍	❍
Drawing (2)	❍	❍	❍	❍
Throwing (3)	❍	❍	❍	❍
Scissors (4)	❍	❍	❍	❍
Toothbrush (5)	❍	❍	❍	❍
Knife (without fork) (6)	❍	❍	❍	❍
Spoon (7)	❍	❍	❍	❍
Broom (upper hand) (8)	❍	❍	❍	❍
Striking a Match (match) (9)	❍	❍	❍	❍
Opening a Box (lid) (10)	❍	❍	❍	❍

BAI Below is a list of common symptoms of anxiety. Please carefully read each item in the list. Indicate how much you have been bothered by that symptom during the past month, including today, by circling the number in the corresponding space in the column next to each symptom.

	0 - Not a all (1)	1 - Mildly, but it did not bother me much (2)	2 - Moderately; it was not pleasant at times (3)	3 - Severely; it bothered me a lot (4)
Numbness or tingling (1)	❍	❍	❍	❍
Feeling hot (2)	❍	❍	❍	❍
Wobbliness in legs (3)	❍	❍	❍	❍
Unable to relax (4)	❍	❍	❍	❍
Fear of worst happening (5)	❍	❍	❍	❍
Dizzy of lightheaded (6)	❍	❍	❍	❍
Heart pounding/racing (7)	❍	❍	❍	❍
Unsteady (8)	❍	❍	❍	❍
Terrified or afraid (9)	❍	❍	❍	❍
Nervous (10)	❍	❍	❍	❍
Feeling of choking (11)	❍	❍	❍	❍
Hands trembling (12)	❍	❍	❍	❍
Shaky/unsteady (13)	❍	❍	❍	❍
Fear of losing control (14)	❍	❍	❍	❍
Difficulty in breathing (15)	❍	❍	❍	❍
Fear of dying (16)	❍	❍	❍	❍
Scared (17)	❍	❍	❍	❍
Indigestion (18)	❍	❍	❍	❍
Faint/lightheaded (19)	❍	❍	❍	❍
Face flushed (20)	❍	❍	❍	❍
Hot/cold sweats (21)	❍	❍	❍	❍

BDI Please read each group of statements carefully, then pick out the one statement in each group which best describes the way you have been feeling during the past week, including today. If several statements in the group seem to apply equally well, simply choose the statement that has the largest number.

BDI.1 Sadness
- 0 I do not feel sad. (1)
- 1 I feel sad much of the time. (2)
- 2 I am sad all the time. (3)
- 3 I am so sad or unhappy that I can't stand it. (4)

BDI.2 Pessimism
- 0 I am not discouraged about my future. (1)
- 1 I feel more discouraged about my future than I used to be. (2)
- 2 I do not expect things to work out for me. (3)
- 3 I feel my future is hopeless and will only get worse. (4)

BDI.3 Past Failure
- 0 I do not feel like a failure. (1)
- 1 I have failed more than I should have. (2)
- 2 As I look back, I see a lot of failures. (3)
- 3 I feel I am a total failure as a person. (4)

BDI.4 Loss of Pleasure
- 0 I get as much pleasure as I ever did from the things I enjoy. (1)
- 1 I don't enjoy things as much as I used to. (2)
- 2 I get very little pleasure from the things I used to enjoy. (3)
- 3 I can't get any pleasure from the things I used to enjoy. (4)

BDI.5 Guilty Feelings
- 0 I don't feel particularly guilty. (1)
- 1 I feel guilty over many things I have done or should have done. (2)
- 2 I feel quite guilty most of the time. (3)
- 3 I feel guilty all of the time. (4)

BDI.6 Punishment Feelings
- 0 I don't feel I am being punished. (1)
- 1 I feel I may be punished. (2)
- 2 I expect to be punished. (3)
- 3 I feel I am being punished. (4)

BDI.7 Self Dislike
- 0 I feel the same about myself as ever. (1)
- 1 I have lost confidence in myself. (2)
- 2 I am disappointed in myself. (3)
- 3 I dislike myself. (4)

BDI.8 Self Criticalness

- 0 I don't criticize or blame myself more than usual. (1)
- 1 I am more critical of myself than I used to be. (2)
- 2 I criticize myself for all of my faults. (3)
- 3 I blame myself for everything bad that happens. (4)

BDI.9 Suicidal Thoughts or Wishes

- 0 I don't have any thoughts of killing myself. (1)
- 1 I have thoughts of killing myself, but I would not carry them out. (2)
- 2 I would like to kill myself. (3)
- 3 I would kill myself if I had the chance. (4)

BDI.10 Crying

- 0 I don't cry any more than I used to. (1)
- 1 I cry more than I used to. (2)
- 2 I cry over every little thing. (3)
- 3 I feel like crying but I can't. (4)

BDI.11 Agitation

- 0 I am no more restless or wound up than usual. (1)
- 1 I feel more restless or wound up than usual. (2)
- 2 I am so restless or agitated that it's hard to stay still. (3)
- 3 I am so restless or agitated I have to keep moving or doing something. (4)

BDI.12 Loss of Interest

- 0 I have not lost interest in other people or activities. (1)
- 1 I am less interested in other people or things than before. (2)
- 2 I have lost most of my interest in other people or things. (3)
- 3 It's hard to get interested in anything. (4)

BDI.13 Indecisiveness

- 0 I make decisions about as well as ever. (1)
- 1 I find it more difficult to make decisions than usual. (2)
- 2 I have much greater difficulty in making decisions than I used to. (3)
- 3 I have trouble making any decisions. (4)

BDI.14 Worthlessness

- 0 I do not feel I am worthless. (1)
- 1 I don't consider myself as worthwhile or useful as I used to. (2)
- 2 I feel more worthless as compared to other people. (3)
- 3 I feel utterly worthless. (4)

BDI.15 Loss of Energy

- 0 I have as much energy as ever. (1)
- 1 I have less energy than I used to have. (2)
- 2 I don't have enough energy to do very much. (3)
- 3 I don't have enough energy to do anything. (4)

BDI.16 Change in Sleeping Pattern
- 0 I have not experienced any change in my sleeping pattern. (1)
- 1a I sleep somewhat more than usual. (2)
- 1b I sleep somewhat less than usual. (3)
- 2a I sleep a lot more than usual. (4)
- 2b I sleep a lot less than usual. (5)
- 3a I sleep most of the day. (6)
- 3b I wake up 1-2 hours early and can't get back to sleep. (7)

BDI.17 Irritability
- 0 I am no more irritable than usual. (1)
- 1 I am more irritable than usual. (2)
- 2 I am much more irritable than usual. (3)
- 3 I am irritable all the time. (4)

BDI.18 Change in Appetite
- 0 I have not experienced any change in my appetite. (1)
- 1a My appetite is somewhat less than usual. (2)
- 1b My appetite is somewhat greater that usual. (3)
- 2a My appetite is much less than before. (4)
- 2b My appetite is much greater than usual. (5)
- 3a I have no appetite at all. (6)
- 3b I crave food all the time. (7)

BDI.19 Concentration Difficulty
- 0 I can concentrate as well as ever. (1)
- 1 I can't concentrate as well as usual. (2)
- 2 It's hard to keep my mind on anything for very long. (3)
- 3 I find I can't concentrate on anything. (4)

BDI.20 Tiredness or Fatigue
- 0 I am no more tired or fatigued than usual. (1)
- 1 I get more tired or fatigued more easily than usual. (2)
- 2 I am too tired or fatigued to do a lot of things I used to do. (3)
- 3 I am too tired or fatigued to do most of the things I used to do. (4)

BDI.21 Loss of Interest in Sex
- 0 I have not noticed any recent change in my interest in sex. (1)
- 1 I am less interested in sex than I used to be. (2)
- 2 I am much less interested in sex now. (3)
- 3 I have lost interest in sex completely. (4)

Q1 We would like to learn what you did and how you felt yesterday. Because many people find it difficult to remember exactly what they did and experienced, we will do this gradually.To begin, please select the day of the week that yesterday was:

- Monday (1)
- Tuesday (2)
- Wednesday (3)
- Thursday (4)
- Friday (5)
- Saturday (6)
- Sunday (7)

Q3 On the next page, please describe your day. Think of your day as a continuous series of scenes or episodes in a film. Give each episode a brief name that will help you remember it (for example, "commuting to work," or "at lunch with B," where B is a person or a group of people). There is one page for each part of the day - morning (from waking up until just before lunch), afternoon (from lunch until just before dinner), and evening (from dinner until you went to bed). There is room to list 5 episodes for each part of the day, although it is not necessary to use all of the spaces - use the breakdown of your day that makes the most sense to you and best captures what you did and how you felt.Try to remember each episode in detail, and write a few words that will remind you of exactly what was going on. Also, try to remember how you felt and what your mood was like.

Q5 Morning (from waking up until just before lunch): Morning Episode 1-5

Q16 Afternoon (from lunch until just before dinner): Afternoon Episode 1-5

Q26 Evening (from dinner until just before you went to sleep): Evening Episode 1-5

The questions below were repeated for each of 15 episodes specified above.

Q24 Now, we would like to know how you felt during those episodes. For each episode, there are several questions about what happened and how you felt.

Answer If Morning (from waking up until just before lunch) Morning Episode 1 Text Response Is Not Empty

Q26 Morning Episode 1 Name: ${q://QID5/ChoiceTextEntryValue} What were you doing? (Please check all that apply.)

- ❑ Commuting (1)
- ❑ Preparing food (2)
- ❑ Shopping (3)
- ❑ Taking care of your children (4)
- ❑ Doing housework (5)
- ❑ Praying/Worshipping/Meditating (6)
- ❑ Eating (7)
- ❑ Watching TV (8)
- ❑ Socializing (9)
- ❑ Computer/Internet/Email (10)
- ❑ Napping/Resting (11)
- ❑ On the phone (12)
- ❑ Relaxing (13)
- ❑ Exercising (14)
- ❑ Intimate relations (15)
- ❑ Working (16)
- ❑ Other (Please specify) (17)

Answer If Morning (from waking up until just before lunch) Morning Episode 1 Text Response Is Not Empty

Q28 Where were you?

- ❍ At Home (1)
- ❍ At Work (2)
- ❍ Somewhere else (3)

Answer If Morning (from waking up until just before lunch) Morning Episode 1 Text Response Is Not Empty

Q30 Were you interacting with anyone (including on the phone, in a teleconference, etc.)?

- ❍ Yes (1)
- ❍ No (2)

Answer If Morning (from waking up until just before lunch) Morning Episode 1 Text Response Is Not Empty

Q32 If you were interacting with someone, who was it? (Please check all that apply.)

- ❑ Spouse/Significant other (1)
- ❑ Friends (2)
- ❑ Co-workers (3)
- ❑ Clients/Customers (4)
- ❑ Students/Patients (5)
- ❑ My children (6)
- ❑ Parents/Relatives (7)
- ❑ Boss (8)
- ❑ Other people not listed (9)

Answer If Morning (from waking up until just before lunch)   Morning Episode 1 Text Response Is Not Empty

Q34 To what extent did you feel each of the following during this episode (with 0 corresponding to not at all and 6 corresponding to the maximum amount)?

______ Amusement (1)
______ Anger (2)
______ Awe (3)
______ Boredom (4)
______ Contentment (5)
______ Disgust (6)
______ Dissatisfied (7)
______ Downhearted (8)
______ Embarrassment (9)
______ Excitement (10)
______ Fear (11)
______ Gratitude (12)
______ Guilt (13)
______ Happiness (14)
______ Love (15)
______ Pleased (16)
______ Pride (17)
______ Sadness (18)
______ Serenity (19)
______ Tired (20)

APPENDIX E – Stimuli Information

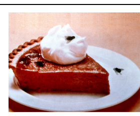
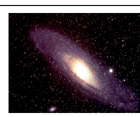
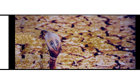
Emotion Category	IAPS			Mikels' norm			
	IAPS #	Valence	Arousal	Awe	Excite	Fear	Disgust
Awe	5300	6.91	4.36	5.57	4.20		
Awe	5594	7.39	4.15	5.27	3.47		
Awe	5600	7.57	5.19	5.07	3.68		
Awe	5830	8.00	4.92	4.10	3.15		
Awe	5890	6.67	4.60	4.88	3.68		
Awe	1942	6.26	4.01	3.70	2.95		
Awe	5982	7.61	4.51	4.68	3.47		
Awe	5990	6.54	4.44	4.55	2.97		
Awe	5991	6.55	4.01	4.17	2.97		
Awe	7580	7.51	4.59	5.07	3.62		
Excite	8031	6.76	5.58	4.12	5.05		
Excite	4599	7.12	5.69	2.87	4.30		
Excite	1999	7.43	4.77	4.58	3.97		
Excite	2216	7.57	5.83	3.02	4.52		
Excite	2340	8.03	4.90	4.53	3.68		
Excite	2345	7.41	5.42	4.30	4.03		
Excite	8120	7.09	4.85	4.05	3.50		
Excite	8220	6.50	5.19	3.52	4.33		
Excite	8420	7.76	5.56	4.12	3.77		
Excite	8461	7.22	4.69	4.10	3.85		
Fear	1052	3.50	6.51			3.30	2.32
Fear	1110	3.84	5.96			3.18	2.13
Fear	1113	3.81	6.06			3.38	2.37
Fear	1301	3.70	5.77			3.23	1.95
Fear	1930	3.79	6.42			3.60	1.90
Fear	1931	4.00	6.80			3.52	1.90
Fear	5971	3.49	6.65			3.28	1.70
Fear	5972	3.85	5.34			3.37	1.52
Fear	6370	2.70	6.44			3.83	2.60
Fear	9620	2.70	6.11			3.58	2.10
Disgust	9182	3.52	4.98			1.90	3.75
Disgust	9390	3.67	4.14			1.38	3.15
Disgust	7360	3.59	5.11			1.58	4.13
Disgust	7361	3.10	5.09			2.75	4.40
Disgust	3250	3.78	6.29			2.12	5.30
Disgust	8230	2.95	5.91			1.92	4.28
Disgust	9042	3.15	5.78			2.18	5.15
Disgust	9490	3.60	5.57			3.32	4.82

Disgust	9373	3.38	5.01			1.60	4.15
Disgust	9290	2.88	4.40			1.72	4.07
Neutral	2308	5.09	2.94				
Neutral	2020	5.68	3.34				
Neutral	2411	5.07	2.86				
Neutral	2880	5.18	2.96				
Neutral	5390	5.59	2.88				
Neutral	5731	5.39	2.63				
Neutral	7026	5.38	2.63				
Neutral	7041	4.99	2.60				
Neutral	7950	4.94	2.28				
Neutral	7179	5.06	2.88				

APPENDIX F – Stimulus Rating Survey

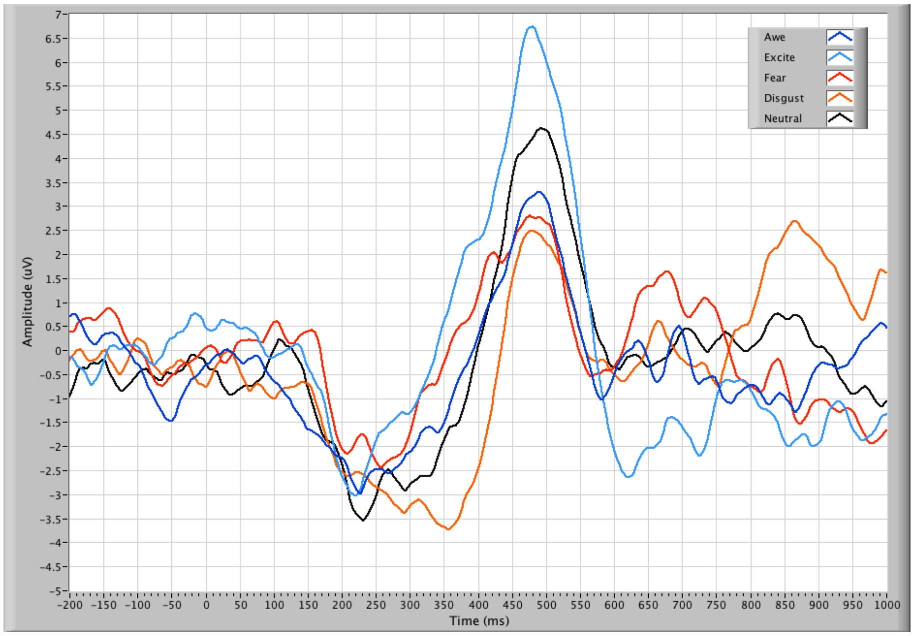
One example was given at the top of all stimuli. Same rating questions were repeated for each stimulus.

Name: ________________________

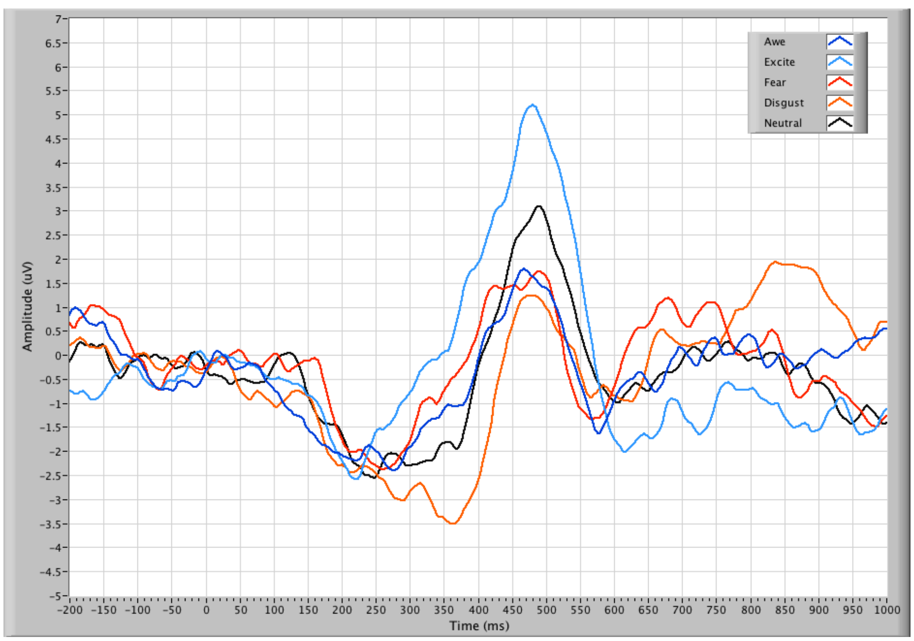
Image#	Image	Emotion
Example		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
1942		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
1999		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
1052		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
7360		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
2038		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
5300		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
2216		Neutral Awe Excitement Fear Disgust 0 1 2 3 4 5 6
1110		Neutral Awe Excitement Fear Disgust

APPENDIX G – ERP Waveforms

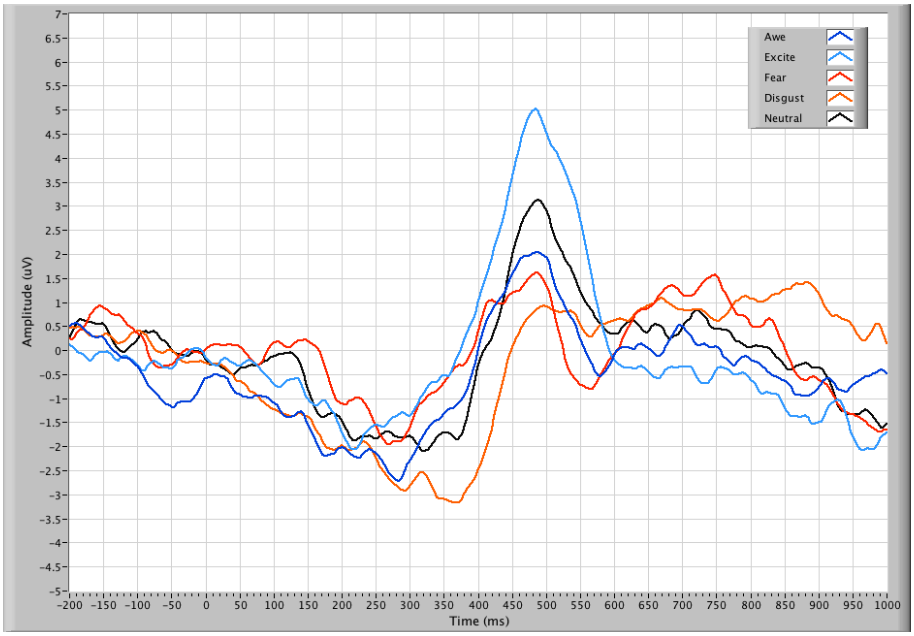
Fp1/2



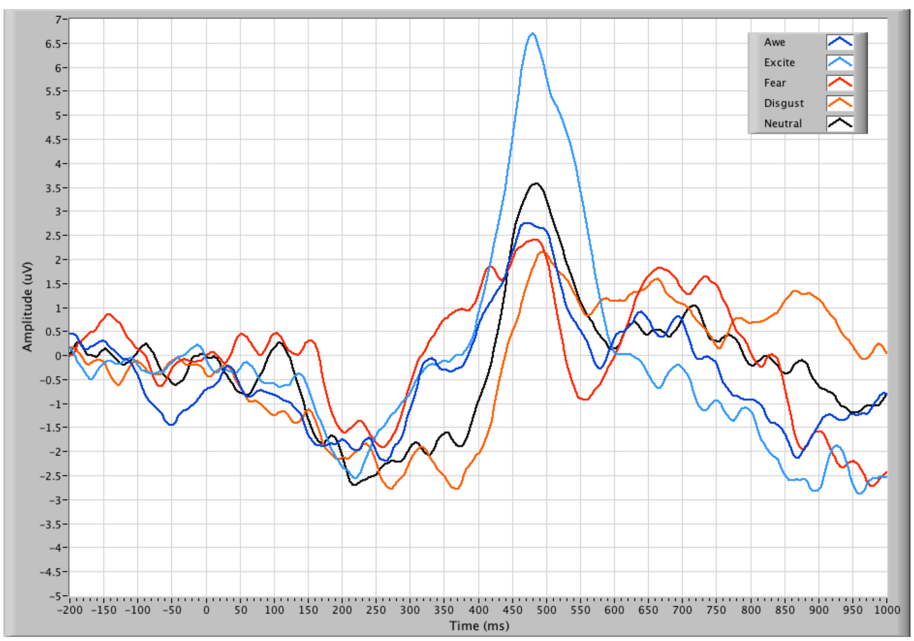
F7/8



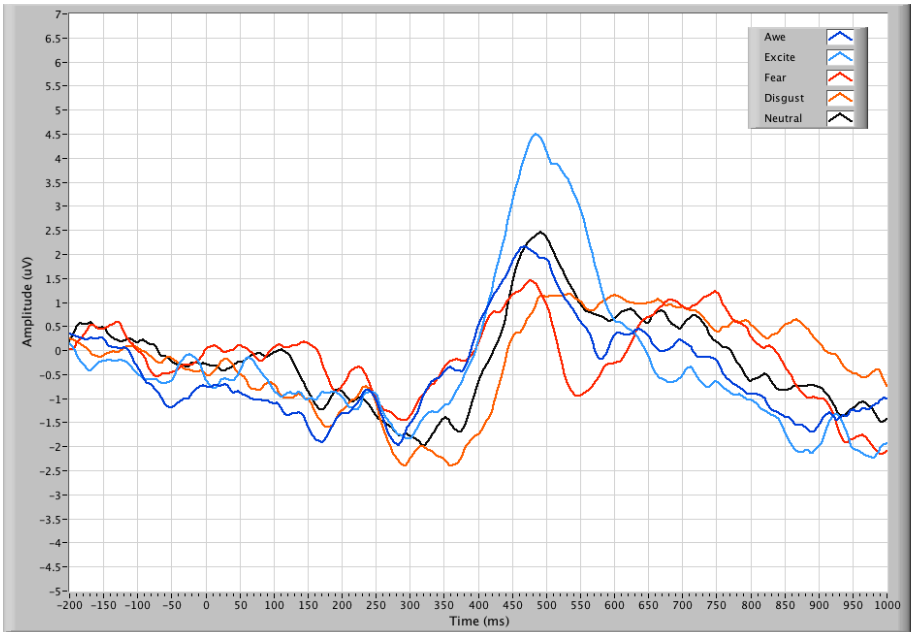
FC7/8


Awe
Excite
Fear
Disgust
Neutral
Amplitude (uV)
Time (ms)
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000

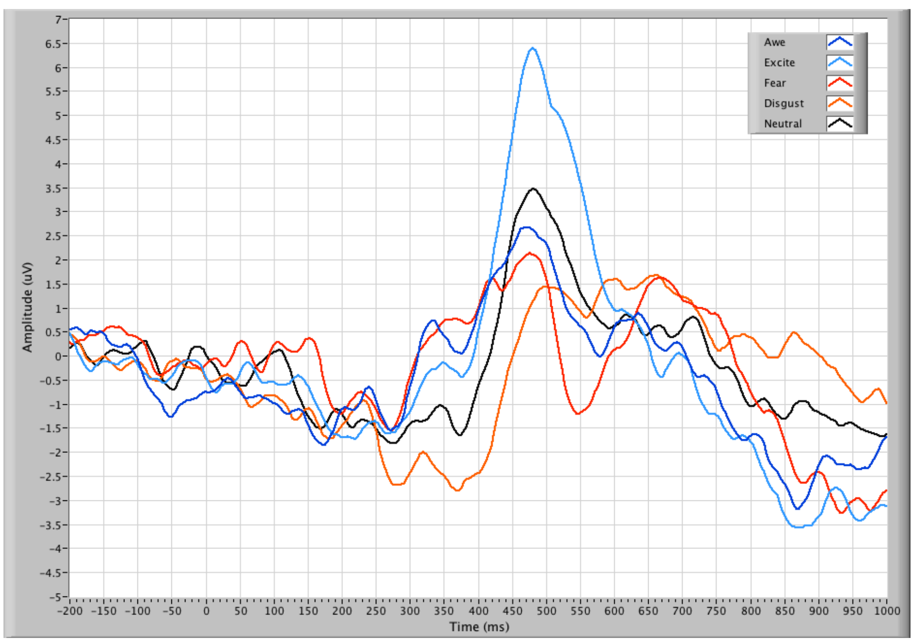
FC3/4


Awe
Excite
Fear
Disgust
Neutral
Amplitude (uV)
Time (ms)
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-200 -150 -100 -50 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000

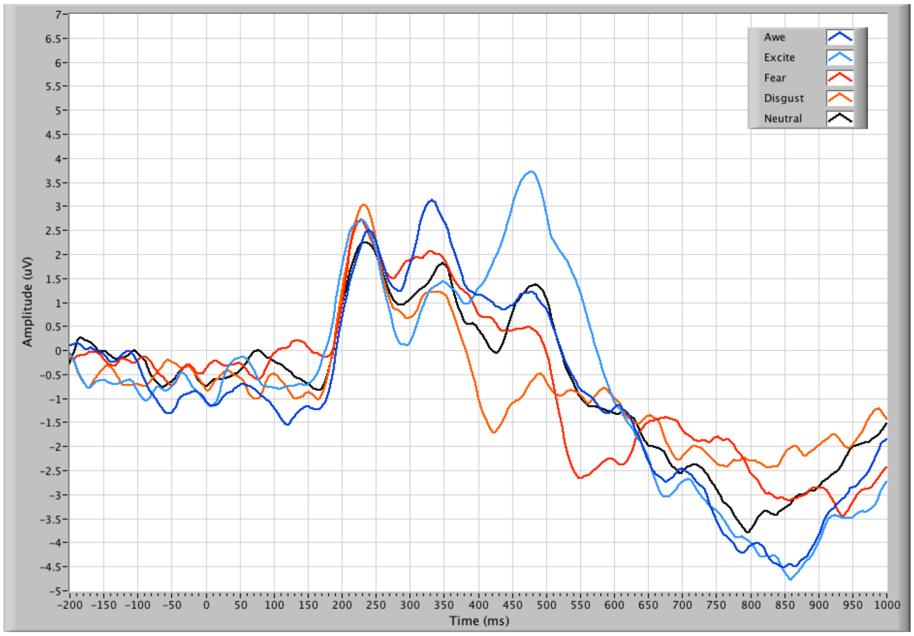
T7/8


Awe
Excite
Fear
Disgust
Neutral
Amplitude (uV)
Time (ms)

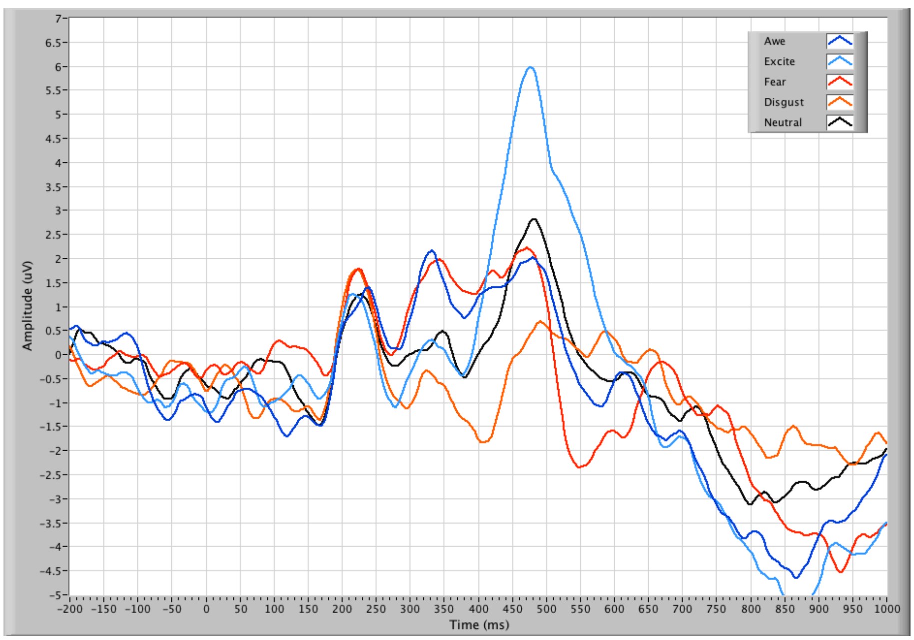
C3/4


Awe
Excite
Fear
Disgust
Neutral
Amplitude (uV)
Time (ms)

P7/8


Awe
Excite
Fear
Disgust
Neutral
Amplitude (uV)
Time (ms)

P3/4


Awe
Excite
Fear
Disgust
Neutral
Amplitude (uV)
Time (ms)

APPENDIX H – Comprehensive ERP Literature

Author	Stimulus From	Emotion Category	Conditions	Subjects	ERP Components	ERP Calculation	Result
(Palomba et al., 1997)	Affective Pictures, IAPS	3 (positive, negative, neutral)		20, 17F/3M	P2 (218), N2 (282), P3 (351), N400, interval 400-600, interval 600-900	Mean amplitude	N2: pleasant~unpleasant>neutral P3: pleasant~unpleasant>neutral 400-600: pleasant > neutral~unpleasant Pz always more positive than Cz No latency difference
(Cuthbert et al., 2000)	Affective Pictures, IAPS	3 (positive, negative, neutral)		37, 14F/23M (34 analyzed)	P2 (200-300, mean 210), N2 (200-300, mean 274), P3 (300-400, mean 373), interval 400-700	Mean amplitude	P2: pleasant>neutral P3: pleasant>unpleasant~neutral Interval 400-700: pleasant~unpleasant>neutral Power: Pz>Cz>Fz Extended duration of the slow wave for affective stimuli (~6s) Frontal sites positivity: pleasant>unpleasant Parietal sites positivity: emotional> neutral
(Wood & Kisley, 2006)	Affective Pictures, IAPS	3 (positive, negative, neutral)		40, 20Young/20 Old	LPP	Peak amplitude	LPP: negative~positive>neutral; Pz>Cz,Fz Older adults: small bias in Pz, longer latency
(Schupp, Stockburger, Bublatzky et al., 2007)	Affective Pictures, IAPS	3 (positive, negative, neutral)	Task (relevant stimuli vs. irrelevant stimuli)	16, 8F/8M, RH, 20-32	N2 (150-350), P3b	Mean amplitude	EPN: pleasant, unpleasant>neutral; high task demand compete with emotional processing P3b: Increase task target relevance increases
(Meinhardt & Pekrun, 2003)	Affective Pictures, IAPS	3 (positive, negative, neutral) + no picture	Oddball task (maintain internal count of target tomes)	20, RH	P3	Mean amplitude	P3: target>nontarget; frontal<parietal; pos~neg<neutral
(Conroy & Polich, 2007)	Affective Pictures, IAPS	3 (positive, negative, neutral)		12, 12F	N100, P200, N200, P300	Peak amplitude, peak	P3: negative<postivie~neutral; left frontal No parietal P3 valence effects,

						latency	where arousal-related activity is strongest
(Dolcos & Cabeza, 2002)	Affective Pictures, IAPS	3 (positive, negative, neutral)		15, 15F, RH	early epoch (500-800), late epoch (800-1200)	Mean amplitude	Parietal: sensitive to arousal Frontocentral: sensitive to both arousal and valence Memory effect: emotional>neutral
(Codispoti et al., 2007)	Affective Pictures, IAPS	3 (positive, negative, neutral)	Repetition	24, 12F/12M	early (150-300), late (300-600)	Peak amplitude	150-300: reduced when repeated 300–600: decreased both between and within blocks of repetitions; neutral pictures do not show LPP in the final block
(Codispoti et al., 2012)	Affective Pictures, IAPS	3 (positive, negative, neutral)	Color vs. gray scale; Short vs. long duration	16, 8F/8M	LPP	Mean amplitude	Removing color information had no effect on the affective modulation of the LPP, regardless of exposure duration.
(Delplanque et al., 2006)	Affective Pictures, IAPS	3 (positive, negative, neutral)	Oddball task	17, 17F, RH	P3a (TF4, 370), P3b (TF2, 550)	PCA temporal factor	P3a: unpleasant>pleasant, posterior locations P3b: pleasant>unpleasant, frontocentral locations
(N. E. Anderson & Stanford, 2012)	Affective Pictures, IAPS	3 (positive, negative, neutral)	Psychopathy	40, 21F/19M, 20Normal/20 Psychopathic	N1 (50–150), P2 (125–225), N2 (225–350), P3 (250–500), LPP (500-900)	Peak amplitude	Task 1 implicit differentiation: nonpsychopathic individuals exhibited a global, persistent, enhanced positivity for emotional images Task 2 explicit categorization: enhanced negativity at N1 of psycho; similar P3
(Pastor et al., 2008)	Affective Pictures, IAPS	3 (positive, negative, neutral)	Mixed vs. blocked presentation	41, 20F/21M, 18-22 (38 analyzed)	Early (150-300), LPP (400-700), slow wave (1-6s)	Mean amplitudes	Early: positive>neutral~negative; occipital, frontocentral area; blocked>mixed condition Late: positive~negative>neutral; centro-parietal area ; blocked neutral>mixed neutral Slow: neutral>positive~negative; centro-parietal area / positive~negative>neutral; fronto-central area; blocked>mixed/ blocked emotional>blocked

							neutral; occipital area
(Carretié et al., 2004)	Affective Pictures	3 (positive, negative, neutral)	Frame color counting task	37, 28F/9M, 20-48	P1 (105), P2 (180), N2 (240)	Peak amplitude, peak latency	P1: neg>pos~neu (automatic attention captured by negative) P2: neg~pos>neu (automatic attention by negative and positive) N2: pos~neu>neg (attention by positive and non-emotional stimuli)
(Carretié, Mercado, Tapia, & Hinojosa, 2001)	Affective Pictures	3 (positive, negative, neutral)	Correspondence check task (two images presented at once)	35, 29F/6M, RH	P200	Peak amplitude	P200: higher amplitudes and shorter latencies to negative
(Schupp et al., 2007)	Affective Pictures, IAPS	3 (sexual, mutilation, neutral)	Attention-shifting paradigm	16, 8F/8M, RH		Difference	negative ERP:erotica>mutilation>people; temporo-occipital regions P3: target>non-target; centroparietal area; erotica~mutilation>people
(Sabatinelli, Keil, Frank, & Lang, 2013)	Affective Pictures, IAPS	3 (sexual, mutilation, neutral)	EEG with fMRI	20, 7M/13F,	LPP (450-900): 13-channel centro-parietal EPN (150-300): 8-channel bilateral occipito-temporal	Mean amplitude	EPN: Mutilation~Erotic>People LPP: Erotic>Mutilation>People
(Rozenkrants, Olofsson, & Polich, 2008)	Affective Pictures, IAPS	4 (2 level valence * 2 level arousal)	Normal and scrambles pictures	32, 16M/16F,	N1 (120–160), P2 (160– 220), N2 (220–300), P3 (300–450), early slow wave (550– 700), late slow wave (700–850)	Mean component amplitude	LPP - high arousal > low arousal; largest over parietal; both normal and scrambled images

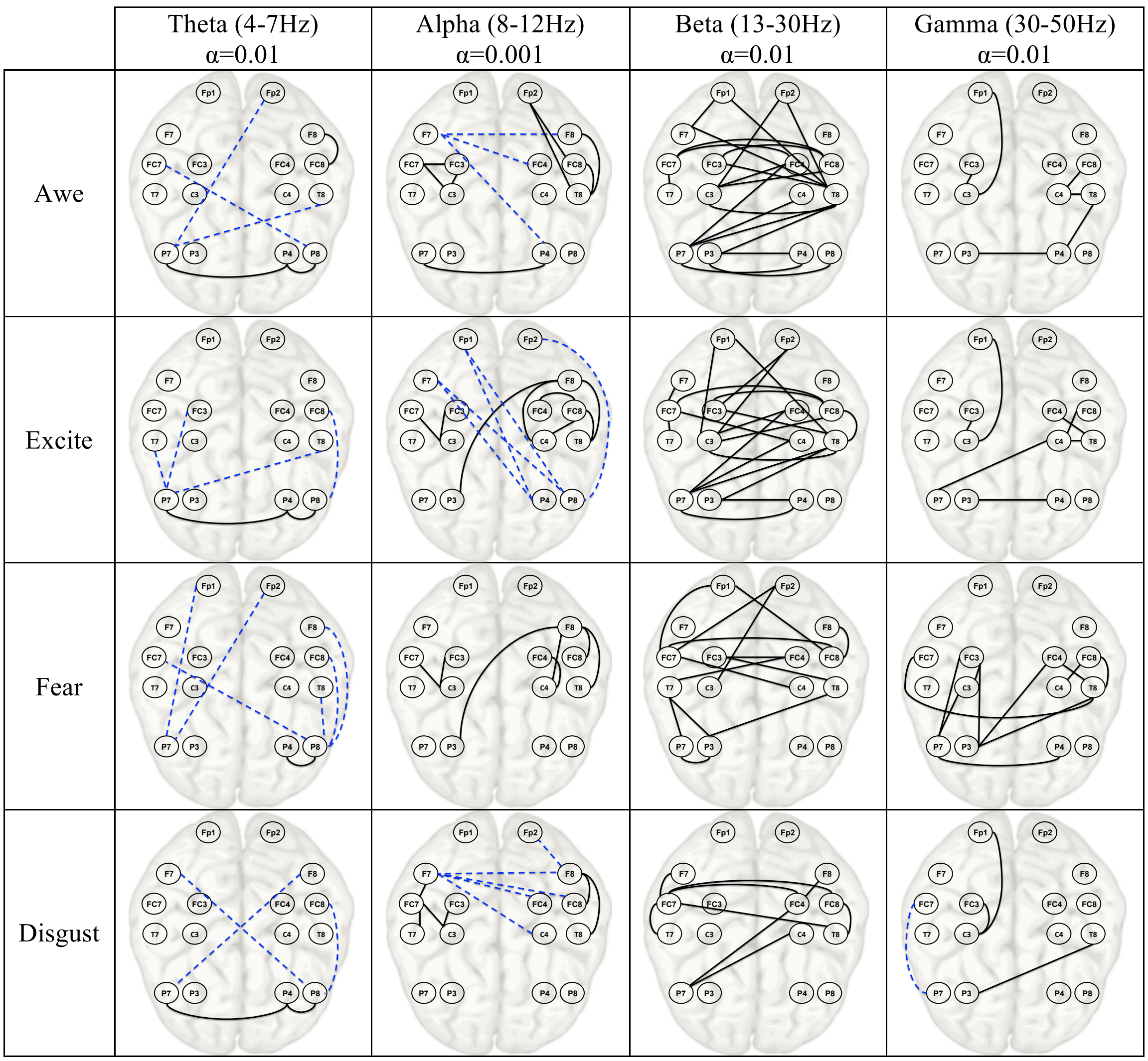
(Rozenkrants & Polich, 2008)	Affective Pictures, IAPS	4 (2 level valence * 2 level arousal)	Gender effect	32, 16M/16F	P1 (80–120), N1 (120–160), P2 (160–220), N2 (220–300), P3 (300–450), early slow wave (SW1, 550–700), late slow wave (SW2, 700–850)	Mean amplitude	P3, SW1, SW2: high>low arousal; negative>positive; over parietal area
(Lithari et al., 2010)	Affective Pictures, IAPS	4 (2 level valence * 2 level arousal)	Gender effect, Oddball paradigm (with normal pictures compared to their “scrambled” counterparts)	28, 14F/14M, RH	P100 (70-130), N100 (90-170), P200 (180-230), N200 (200-300), P300 (300-400)	Peak amplitude, peak latency	P100: Cz, Fz, Pz, low>high arousal N100: Fz, Pz, high>low arousal; female>male when unpleasant P300: Pz, high>low arousal Unpleasant: short latency
(Kaestner & Polich, 2011)	Affective Pictures, IAPS	4 (2 level valence * 2 level arousal)	Passive viewing vs. task	24, 24F, RH	P1 (100–200), N1 (200–350), N2 (300–450), P2 (400–550), P3 (500–750), Slow Wave (700–900)	Mean amplitude	ERP valence main effects were not found (in both conditions) Middle to late components: high arousal>low arousal; unpleasant>pleasant along midline
(Carretié & Iglesias, 1995)	Affective Pictures, IAPS	mixed 4 (happy face, neutral face, grey, landscape)		32, 29F/3M, 21-34	N200, P200 (150-250), N300 (250-350), P300 (350-550), SW (550-900)	Mean amplitude	150-250: G vs. other (lateral), H vs. G, N vs. G, N vs. L (midline) 250-350: H vs. N, H vs. L, G vs. N (T8), G vs. other (Fz), H vs. other, N vs. G (Cz) 350-550: L vs. other (T7), N vs. other (T8) 550-900: L showed difference in T7 and T8; N vs. G, N vs. L (T7), N vs. other (T8)
(Carretié et al., 1997)	Affective Pictures	mixed 4 (nude model, human remain, landscape, building)	Correspondence check task	32, RH, 19-24	P300 (275-325), N300 (350-450)	Mean amplitude	P300: Not significant N300: Parietal (P3,P4,Pz), big N300 from attractive stimulus
(Carretié, Iglesias, & García, 1997)	Affective Paintings	mixed 4 (activating-attractive, activating-	Syllable saying task (related to the stimulus)	31	N200 (150-250), N300 (275-325), P300 (350-450)	Mean amplitude	N200 and P300: no significance N300: repulsive stimulus showed highest N300 in frontal area; attractive stimulus showed

		repulsive, relaxing, neutral)					highest N300 in parietal area
(Schupp, Junghöfer, Weike, & Hamm, 2004)	Affective Pictures, IAPS	mixed 6 (sexual, family, mutilation, threat, neutral object, neutral expression)		16, 14F/2M, 19-27	EPN (200-350; temporo-occipital and centro-medial), LPP (400-500; centro-parietal)	Peak amplitude	EPN: negative>neutral LPP: pos~neg>neu
(Herrmann et al., 2002)	Face by Ekman and Friesen (1976), B&W	3 (happy, sad, neutral) + 1 (building)		16, 8F/8M, RH, 19-42	N1 (172-352), P2 (125-283), P3 (242-500)	Peak amplitude, peak latency	Face>building (significantly large peak at 163) No emotional content effect on ERP
(Balconi & Pozzoli, 2003)	Face by Ekman and Friesen (1976), B&W	6 (happy, sad, angry, surprised, fearful, neutral)	Recognition task (e.g., gender)	18, 10M/8F	N170, N230	Peak amplitude	N230 amplitude: anger~fear~surprise>happy~sad> neutral in anterior (Fz) and posterior (Pz) sites
(Pollak et al., 1997)	Face by Ekman and Friesen (1976), B&W	3 (happy, angry, neutral)	Happy-angry order differed, Happy or angry was target	Exp1: 23 maltreated/21 normal treated children Exp2: 14, 7M/7F	Exp1: P470, P590* Exp2: P364, P440* *P300 criteria	Mean amplitude	P300 non-maltreated children: angry~happy P300 maltreated: angry>happy Latency: maltreated > non-maltreated No differences in accuracy or speed emerged as a function of target condition.
(Paulmann & Pell, 2009)	Face by Pell (2002), B&W	3 (happy, angry, fearful) + 1 (grimace)	Face recognition task	26, 12F/14M, RH, English, mean age 21.2	P200 (150-220), early negativity (220-270), N400 (350-450)	Mean amplitude	P200: grimace>emotional>neutral (left), grimace>emotional, neutral (right) Early Neg (N230): neutral>emotional (left frontal); grimace>emotion (posterior); grimace>neutral (right posterior) N400: grimace>emotional, neutral

(Batty & Taylor, 2003)	Face, B&W	7 (happy, surprise, sad, fearful, disgusting, angry, neutral)		26, 13F/13M, 12RH/14LH	P1 (mean94), N170 (mean140), interval 270-420	Mean amplitude (30 ms window)	P1: did not vary with facial expression N170: fear, disgust, sadness>neutral, happy, surprised N170 latency: positive<negative Interval 260-390: largest emotion effect. Neutral>angry>disgust, fearful
(Bar-Haim, Lamy, & Glickman, 2005)	Face, Japanese and Caucasian facial expressions of emotion (JACFEE)	5 (happy, sad, angry, fearful, neutral)	Anxiety	13, 2M/11F (top quartile out of 66)	Cue evoked: P1 (50-165), N1 (90-215), P2 (120-315) Target evoked: P1 (40-140), N1 (100-200), P3 (200-450)	first major peak	P1 amplitude: fearful < other P1 latency: anxious < other N1 amplitude: fearful > other N1 latency: fearful < other in Oz P2 amplitude: anxious > other in Cz P2 latency: anxious < other
(Wang, Zhu, Bastiaansen, Hagoort, & Yang, 2013)	Words, Chinese names and nouns	3 (positive, negative, neutral)		22, 9M/13F	N1 (90-110), P2 (170-250), remaining(250-1000)	Peak amplitude, peak latency	N1, P2: No effect of emotion category on name Remaining: negative>positive~neutral, latency was shorter for nouns
(Thomas et al., 2007)	Words	2 (threating, neutral)	Stroop effect (word/color)	22, 5M/17F, 18RH/5LH, 18-24	N1 (110-160, Cz), P2 (150-210, Pz), N2 (260-500, Fz), P3 (340-600, Pz)	Peak amplitude	P2 - threat>neutral (left), threat>neutral (right), right>left P3 - threat>neutral No latency difference

APPENDIX I – Coherence

The figure below shows how the depression pattern differed between high and low granular groups. When the high granular group showed more reduction, the channel pair was marked in black solid line, and when the low granular group showed greater suppression, the pair was marked with blue dashed line. Beta oscillation was significantly decreased in high granular group, with less suppression in negative images (fear and disgust).



Neutral