The Psychophysiology of Emotion

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1. Early psychophysiological approaches into the psychophysiology of emotion

Research into the psychophysiology of emotions dates back to the end of the 19th century. In 1884 and 1885, the American philosopher and psychologist William James and the Danish Physiologist Carl Lange independently proposed a very similar physiological theory of emotions. According to the James-Lange theory, emotion inducing sensory stimuli are first received by the cortex that triggers changes in visceral organs and skeletal muscles. The feedback from those peripheral organs travels back to the cortex where the experience of emotions is caused. The James-Lange theory has often been criticized because the autonomic responses occur too slowly to be the cause of emotional feelings. As an alternative, Walter Cannon and Paul Bard proposed in 1927/28 what is called the „thalamic theory“ of emotions. According to the Cannon-Bard theory, emotional stimuli excite both the feeling of emotions in the brain and their expression via the autonomic and somatic nervous system in parallel. Their theory could have been called „hypothalamic“ as well since they regarded the hypothalamus as the source of visceral and skeletal muscular response patterns to emotion eliciting stimuli. In the late thirties, Papez and McLean proposed their famous approach centered on the limbic system in the brain.

A major implication of these theoretical approaches is the existence of a distinct somato-visceral response pattern for each emotional quality. However, in almost one century of research into the psychophysiology of emotions, such distinct patterns have barely been found. A possible solution for this particular problem may be not to look out for patterns of single emotions but try to distinguish a few emotional dimensions by means of their psychophysiological patterns. Determining the dimensionality of emotions has resulted in either two, three or four dimensions. There is a general agreement on two major dimensions; i. e., hedonic value and arousal. However, most of this kind of work has been performed by the application of multidimensional scaling on emotion related adjectives or facial expressions. Psychophysiological patterns, on the other hand, have been mainly related to single emotional qualities such as fear, anger and joy.

2. Psychophysiological pattern approaches and animal models of emotional behavior

As long as there is no clear evidence for the existence of distinct physiological patterns for different emotions, the psychophysiological investigation of emotional states cannot be performed satisfactorily by means of physiological recording only. Different emotions may elicit the same amount of general arousal, thus becoming possibly indistinguishable with respect to their autonomic nervous system (ANS) concomitants. Therefore, in classic psychophysiological emotion research, emotional quality is determined via subjective variables while their quantitative properties are measured by ANS parameters.

Various attempts have been made to obtain emotion specific patterns of physiological reactions, since Ax in 1953 tried to differentiate the effects of anger and fear by means of ANS variables. In his classical experiment, subjects received two conditions in counterbalanced order. In one condition, subjects were annoyed by means of an obnoxious experimenter. In the other condition they were frightened by having electric shock applied to their finger, accompanied by sparkles near the subject, and the experimenter exclaiming that this was a high voltage short-circuit. Differences between anger and fear appeared on seven of 14 physiological measures recorded. However, large individual differences were observed; for example, some of the fearful subjects evidenced higher changes in electrodermal activity

(EDA) than in respiration rate while others showed the reverse pattern. Nevertheless, Ax attributed the observed ANS reactions to certain underlying endocrine patterns as outlined in the next paragraph.

At least eight multivariate studies were performed that attempted to differentiate experimentally induced anger and/or fear by means of ANS variables since Ax's 1953 study. In most of these studies, both emotions yielded higher cardiovascular output (increases in heart rate and blood pressure) compared to resting conditions. An increased EDA has been found for both emotions in two of the studies, while not differing from resting condition in another study. Three of the four studies with a direct comparison of anger and fear found an elevated heart rate (HR) during fear compared to anger. Two of the four studies found a lower diastolic blood pressure and lower tonic electromyographic (EMG) values, while three of them found an increased EDA during fear compared to anger. The existence of a so-called adrenaline-noradrenaline pattern under anger vs. an adrenaline pattern under anxiety as supposed by Ax could only partially be confirmed. By the way, Ax did not obtain measures of catecholamines. He simply concluded that the ANS pattern under anger resembled the expected response to adrenaline and noradrenaline injections, while the ANS pattern under fear resembled the response had adrenaline been injected.

In a well controlled experiment, Stemmler (1989) induced three emotions (fear, anger, and pleasure) to 42 female subjects in a repeated measures design. Fear was induced by tape presentation of a fear-evoking short story being accompanied by an unannounced darkening of the room. Anger was induced by presenting a series of anagrams, most of which were not solvable, which, however, could not be detected by the subjects during the short presentation. Pleasure was induced by positive reinforcement and the announcement of increased payment at the end of the study. Various peripheral physiological measures including palmar skin conductance were obtained. To obtain an additional objective measure of the forehead anxiety sweat, an EDA recording was taken from the forehead. Recordings were continuously taken during the induction of emotions and during interspersed resting phases as well. In addition, several standardized ratings of emotional states were applied. These subjective measures yielded their most pronounced results in the appropriate situational context. However, their sensitivity was less during fear and anger conditions as compared to the pleasure condition. Out of the 34 parameters that were extracted from the physiological recordings, the 14 which significantly differentiated between the reference phases for the three emotions were included in a discriminant analysis, which resulted in different profiles for fear and anger. However, no significant differences between the profiles for pleasure and the other emotions emerged. Multivariate comparisons yielded low EMG values together with peripheral vasoconstriction, low skin temperature, and a low EDA taken from the palms, but an increase of forehead EDA during the fear state. During anger, the forearm EMG and the vasodilatation at the hand and the forehead were increased, and an increase of forehead EDA appeared, too. Stemmler's results did not sufficiently fit those of Ax (1953) with respect to EDA, although the palmar EDA was lowest under fear in both studies.

Recently, Boucsein and Baltissen (1998) performed a series of studies in order to simultaneously differentiate both qualitative and quantitative aspects of emotions by means of psychophysiological measures. First, 23 slides from the IAPS series were judged by 120 subjects with respect to their properties to elicit different emotional qualities. In a second study, 24 subjects were presented two slides from each of the following categories: Erotic happiness, nurturant happiness, fear, sadness, disgust and emotionally neutral. The slides were presented twice in randomized order. During the first presentation, HR, EDA and three facial EMGs (taken from zygomatic major, corrugator supercilii and lateral frontalis muscles) were recorded. The second presentation was performed to obtain subjective ratings of the emotions elicited. In general, the physiological measures used in this study sufficiently differentiated between positive, negative and neutral emotional slides, except for fear. Therefore, in a third study with another 24 subjects, the same slides were presented under two different arousing conditions for each half of the subjects in order to vary the quantitative (arousal) aspect of emotionality. High arousal was induced by

80 dB white noise, while 50 dB noise served as a low-arousal inducing control condition. The same physiological measures as in the second study were recorded, except for the frontalis EMG which was replaced by the finger pulse volume. Instead of generally enhancing the psychophysiological responses, 80 dB noise evoked rather different patterns for the different emotional qualities. Interestingly, the differentiation by means of EDA measures was better under the low-arousal condition but HR differentiated better between the emotion-inducing slides under the high arousal condition. This parallels the findings in the clinical domain that EDA recordings provide highly sensitive parameters for minimal changes such as in general anxiety states, while HR has its major indicator function in high-arousal states of anxiety such as phobias (Boucsein, 1992). In general, fear and disgust inducing slides elicited the most pronounced initial EDR amplitudes. This is in accordance with EDA being regarded as the psychophysiological system with a specific reactivity to negative emotions. However, if an evaluation period as long as 10 seconds was taken into account, presenting erotic happiness-inducing slides resulted in greater EDA as compared to negative emotion-inducing slides. This effect was attenuated by noise.

There are several consequences to be drawn from the hitherto performed research into the use of EDA as an indicator of emotion. First, the level of arousal, i. e., the quantitative aspect of emotionality, is critical to its indicator function. Second, the evaluation interval can be critical as well. Initial response strength may be different from the overall response. Third, a single measure or a single psychophysiological system cannot account for all changes elicited by the different emotional qualities. The problem of how to parallel qualitatively different states of emotion with respect to their quantitative properties remains central to this kind of research. In addition, particular conditions of the experimental design such as counterbalance of the sequence of different emotions may have a strong influence on the results. Various kinds of response specificity as already observed by Ax and systematically treated in the seventies and eighties further complicate multivariate research of emotional states.

Since psychophysiology in its own right apparently cannot provide a theoretically founded base for the differentiation of emotions, results from animal studies have to be considered as well. However, this approach is limited since emotions can be studied only indirectly in animals by the observation of approach and withdrawal behavior as indices of positive and negative emotions. On the other hand, brain mechanism responsible for the respective emotive states can be studied directly by electrical stimulation of pleasure and punishment centers eliciting appetitive and aversive behavior. Furthermore, cellular mechanisms can be studied in animals using single unit recording. Panksepp (1998) distinguished four major emotional operating systems by their genetically coded neural circuits in rats, the outcomes of which result in typical behavioral patterns. Although his „rage“ system can be regarded as opposite to his „seeking“ system, the two other systems „fear“ and „panic“ do not compare to bipolar dimensions as found in studies with human subjects, nor can the dimensions be regarded as orthogonal. Panksepp's work constitutes an excellent example of a conceptual framework for basic emotions in animals, including their brain sources and transmitter systems predominantly involved. Nevertheless, there is no unequivocal relationship to the dimensionality of emotions found in humans. The same holds for other models of animal emotionality, such as the one proposed by Rolls (1999). Based on a strict reinforcement theory approach, he formed a two-dimensional system with positive vs. negative reinforcement as a first and omission or termination of positive vs. negative reinforcement as a second dimension. Instead of having an intensity or arousal dimension of its own, Rolls incorporated the intensity aspect in each of his dimensions. For example, by increasing the strength of the positive reinforcer, the resulting emotion was suggested to shift from pleasure over elation to ecstasy.

Although animal research has revealed a low dimensionality of emotions as well, there have been only very few suggestion so far how to relate the predominantly subcortical structures to the psychophysiological concomitants of human emotions (Boucsein, 1999). Furthermore, a wide gap remains between the relatively simple structure of emotional behavior in animals and the variety of emotional experiences in humans. Despite this persisting problem, the nature of the emotion dimensionality cannot be revealed without a deliberate neurophysiological model of how emotions are decoded in subcortical and cortical areas of the brain. Therefore, results from animal studies constitute an important contribution to the neurophysiological modeling of the emotion detection process outlined in the next section.

3. Facial expression and emotional responses in the central nervous system

In an attempt to overcome the persisting problems with the classical approaches mentioned in the previous section, Sokolov and Boucsein (2000) suggested to start with modeling the afferent brain processes instead of focusing on the response side. The model proposed by them is based on a hypothetical analogy between coding in color vision and coding of emotion related stimulus properties such as emotion words or emotion expressing faces. Both the color and the emotion systems have in common that a wide variety of phenomena can be reduced to a system of low dimensionality. Therefore, a common principle is suggested for the central nervous system (CNS) processing of colors and emotions. A possible analogy between color space and emotion space was already pointed out by Schlosberg (1952). In a similar way as saturated colors are located on a circumference in a two-dimensional system, the axes of which represent red-green and blue-yellow, Schlosberg suggested to arrange facial expressions of emotions on a circumference within a two-dimensional system, locating more pronounced emotional expressions near the periphery and neutral expressions near the center.

Similarly to Schlosberg who was the first one who described the location of emotional qualities on a circumplex structure, Russell (1980) suggested a circumplex structure of emotion space as well. Both authors assumed two dimensions by which the different emotions can be described. Moving from a two-dimensional to a four-dimensional solution for the emotion space as suggested by the present authors will result in the replacement of the circumplex structure location found in the two-dimensional space by the location of emotions on a hypersphere in the four-dimensional space. The surface of such a hypersphere will be occupied by emotion detectors, so that the difference between two emotions corresponds to the distance between the respective emotion detectors on the hypersphere (Sokolov & Boucsein, 2000).

The particular approach into the psychophysiological investigation of the emotion space proposed by Sokolov and Boucsein applies multidimensional scaling techniques to vector coding of psychophysiological responses emerging from differences between successively presented emotion relevant stimuli. Vector coding in neuronal networks has been found to constitute a basic principle of information processing in the study of color vision, targeting responses such as head and eye movements, and instrumental conditioning in fish, rabbits and monkeys (Sokolov, 1998). Therefore, it may be suggested that a similar principle of vector coding may underlie the processing of emotion relevant information as well. As a consequence, techniques applied to reveal the structure of color space should be applicable to the emotion space as well.

Facial expression is regarded as a powerful emotion relevant stimulus category because it constitutes a basic channel for social communication in humans as well as in other primates (Izard, 1971). Therefore, facial expressions can be used as a tool to investigate the dimensionality and neuronal basis of the emotion space. Within the psychophysiological approach in this area, specific features of the event related potential (ERP) have been successfully used as the first step for determining the dimensionality of emotions. Additionally, emotions may be characterized by a set of specific responses of the motor and the autonomic system triggered by respective command neurons. Furthermore, emotions can be regarded as subjective phenomena similar to visual, auditory and somatosensory perceptions suggesting selective „emotion detector neurons“ as a basis for emotional experiences (Sokolov, 1998). The low dimensionality of both color and emotion spaces can be explained by the limited number of neurons preceding a fine grained discrimination of colors and emotions at the higher order detector level.

There are at least two different cortical processes involved in the analysis of faces: Individuality and emotional expression. Although the recognition of an individual face is of major importance for social interactions, misjudging an emotional facial expression may have even more severe consequences than a failure to recognize an already known person. Therefore, it is an important scientific goal to reveal the structures and processes involved in the analysis of identifying the emotional contents of faces. It is now widely accepted that different cortical regions are involved in analyzing the identity of a face and its emotional expression (Damasio, Tranel, & Damasio, 1990). As has been inferred from the neurological disease of prosopagnosia, the inferior temporal gyrus is very likely involved in the recognition of familiar faces, while at least in primates (macaque monkeys) the anterior part of the superior temporal sulcus is involved in the final analysis of the emotional expression of faces (Hasselmo, Rolls, & Baylis, 1989).

A number of studies have used ERPs to reveal both temporal and topographical features during cortical processing of faces with different emotional content. Laurian, Bader, Lenares and Oros (1991) found an increased P300 over right centro-parietal sites for photographs of angry or friendly as compared to neutral faces. A similar result was obtained by Carretie and Iglesias (1995) who obtained a larger P300 while presenting a photograph of happy compared to neutral faces, predominantly over temporal sites, and a greater positivity in a late slow wave component elicited by happy faces, being more visible in midline frontal and central sites as in temporal areas. Such an increase in a midline positive slow wave while viewing emotionally charged vs. neutral schematic faces was also found by Vanderploeg, Brown and Marsh (1987). In contrast to Carretie and Iglesias (1995), these authors obtained a greater positivity was revealed in the P300 range during the presentation of neutral as compared to emotionally charged faces.

Hemispheric specialization is likely to play a role in the processing of emotional charged stimuli such as faces. In the study of Vanderploeg et al. (1987), a greater P300 amplitude for neutral compared with emotional faces showed up in the left hemisphere, while the slow wave amplitude was greater to emotional compared to neutral faces in the right hemisphere. However, Carretie and Iglesias (1995) did not find hemispheric asymmetries in their ERPs over temporal recording sites. Furthermore, there exists a possibility of affective valence being lateralized, since the right hemisphere has been found to be particular sensitive for negative stimuli, while activity in the left frontal lobe dominated during positive stimuli (Davidson, 1983). In particular, happy faces were recognized more quickly when presented to the right visual field, while sad faces were more quickly recognized in the left visual field.

However, the use of ERPs has not yet produced unequivocal results with respect to the „where“ and „when“ of the cortical analysis of facially expressed emotions. Methodological differences in stimulus features, ISIs, or number and location of recording sites may have contributed to that diversity. In addition, most ERP studies on facial emotional expression are hampered with possible interferences of tasks that may directly influence ERPs, such as verbal judgement of emotional connotation, detection of a specific target, or a stimulus discrimination task (Sokolov & Boucsein, 2000). A major problem is still the experimental separation between emotional and individual features of faces. Using photographs of real faces will necessarily confound individuality and emotion unless the stimulus set is restricted to the different emotional expressions of a single actor. Line drawings of real faces may still constitute too complex stimuli if a pure manipulation of the emotional content is intended. Therefore, Sokolov and Boucsein recommended the use of schematic faces that can be manipulated easily with respect to their emotional expression. By means of such stimuli, an artificial prosopagnosia effect can be produced, thus preventing the cortical areas that are involved in the recognition of facial identity from being involved in the stimulus analysis.

Following this line, Boucsein, Schaefer, Sokolov and Schroeder (2000) performed a carefully controlled study in order to reveal the cortical areas involved in the encoding of emotions expressed in schematic faces. Twenty-five subjects were presented a positive, a negative, and a neutral computer generated face with random inter-stimulus intervals in a within-subjects design, together with four meaningful and four meaningless control stimuli made up from the same elements. Frontal, central, parietal, and temporal ERPs were recorded from each hemisphere. It was expected that switching between faces of positive and negative emotional content would produce smaller P300 amplitudes compared to the switches between emotional and neutral faces, since the emotion-on-off effect in the latter case was suggested to require a greater amount of information processing than merely detecting specific emotional features. In addition the P300 component that has been found in most earlier studies, a pronounced increase in the N150 range appears in case a neutral face is replaced by an emotional one. Furthermore, the positive face elicits increases in the parietal range when alternated with the negative face. No pronounced lateralization effects are found but some emphasis of the N150 component in temporal and parietal locations that needs further topographical research.

The use of schematic faces as emotional stimuli has been demonstrated to be a useful tool in the investigation of emotional effects not interfering with the recognition of face identity. In particular, a hitherto disregarded ERP component in the range below 200 ms looks promising for further evaluation of the cortical mechanisms involved in the analysis of the emotional content of facial stimuli. Brain mapping studies are required in the future to reveal the exact lateralization including a possible topography of these cortical activities.

4. The use of emotion psychophysiology in "Kam-Sung" engineering

The term „kamsung" is often used in the engineering area in Korea and in Japan. In Japan, it is called „kansei". Its lexical meaning is intuitional mental activities related to feeling and desire. Originally, „kansei" referred to a personal ability to discriminate and evaluate the quality of art or the purity of the natural environment (Yagi, 2000). In the field of engineering, kamsung is used to refer to sensitivity and feeling, when a person looks at or has contact with a product. As the final goal, engineers wish to control such qualities as beauty, desirability, comfort, and pleasantness manifested in an industrial product. Therefore, engineers attempt to measure a person's kamsung by using psychophysiological methods in the process of designing products. Nagamachi (1988) proposed „kansei engineering" for using psychological techniques in design of a product. However, engineers in Korea and Japan more recently prefer to use objective physiological methods rather than the more subjective psychological procedures. In Korea, a research project on „kamsung engineering" has been initiated. It is similar to the Japanese project on „Human sensory measurement application technology".

Alpha activity in the EEG has often been used as an index of relaxation and feelings of comfort in many laboratories. However, some of the conclusions remain questionable, especially those suggesting that subjects felt comfortable only when alpha activity appeared (Yagi, 2000). Therefore, Yoshida and Kaneko (1989) proposed a new method for analyzing alpha wave activity, developing a system to estimate the fluctuation of the frequencies in the alpha band. They reported that the coefficient of fluctuation was related to the subjective feeling of comfort rather than to the appearance of alpha activity. Kato and Yagi (1993) have attempted to discriminate between pleasant and unpleasant feelings using facial muscle activities. The majority of subjects showed a uniform pattern in the facial muscle activities during the experience of unpleasant smells. However, they could not obtain unique muscle patterns associated with pleasant smells. In accordance with the results reported in the first section, it appeared to be more difficult to assess feelings of pleasantness by means of psychophysiological methods than determining concomitants of negative emotions. Thus, the study of kamsung is still in the early stages of development (Backs & Boucsein, 2000).

In America and Europe, research on kamsung engineering is sparse. Only recently, Boucsein, Schaefer, Schwerdtfeger, Busch & Eisfeld (1999) performed a psychophysiological study on the objective emotional assessment of different foams. Twelve highly trained female panelists served as subjects. They were presented four different tensides (foams) in a counterbalanced order in a carefully controlled experimental session. During a 30 sec touch period and a 30 sec handling period, EDA, HR, pulse volume amplitude, and three facial EMG leads were recorded. Subjective ratings were obtained after each foam presentation. The whole procedure was repeated after a home-use phase. Results were compared with those of a traditional „sensory assessment" and a free hedonic description of the foams. The psychophysiological measures allowed for an excellent prediction of the hedonic qualities of the different foams, and the degree of acceptance by the user could be reliably predicted by the results of the objective emotional assessment.

It remains an important goal for the research on kamsung engineering to theoretically back up the ANS and CNS measures used in the field. Basic studies such as reported in the previous sections may be helpful to provide an appropriate theoretical framework.

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