Autonomic and Frontal Electrocortical Responses That Differentiate Emotions Elicited by the Affective Visual Stimulation

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Abstract

Cardiac, respiratory, electrodermal and frontal (F3,F4) EEG responses were analyzed and compared during exposure to slides of International Affective Picture System (IAPS) in the study on 42 students. Physiological responses during 20 s of exposure to slides intended to elicit happiness (nurturant and erotic), sadness, disgust, surprise, fear or anger emotions were quite similar and were expressed in heart rate (HR) deceleration, decreased HR variability (HRV), specific SCR, increased non-specific SCR frequency (N-SCR), and EEG changes exhibited in theta increase, alpha-blocking and increased beta activity, and frontal asymmetry. However, some emotions demonstrated variations of the response magnitudes, enabling to differentiate some pairs of emotions by several physiological parameters. The profiles showed higher magnitudes of HRV and EEG responses in exciting (i.e., erotic) and higher cardiac and respiratory responses in surprise. The most different pairs were exciting-surprise (by HR, HRV, theta, and alpha asymmetry), exciting-sadness (by theta, alpha, and alpha asymmetry), and exciting-fear (by HRV, theta, F3 alpha, and alpha asymmetry). Nurturant happiness yielded the least differentiation. Differences were found as well within negative emotions, e.g., anger-sadness were differentiated by HRV and theta asymmetry, while disgust-fear by N-SCR and beta asymmetry. Obtained results suggest that magnitudes of profiles of physiological variables differentiate emotions evoked by affective pictures, despite that the patterns of most responses were featured by qualitative similarity in given passive viewing context.

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Introduction

The topic of peripheral emotion-specificity has been studied for many years since autonomic nervous system (ANS) mediated responses are closely associated with emotions [1, 3, 6, 7, 12, 15, 16, 19, 21, 22, 24, 26, 28, 30, 33, 34]. Electrocortical responses emotion-specificity has been explored only in few studies [8, 9, 10, 11, 27, 29], whereas even fewer addressed combined ANS and

CNS measures to differentiate emotions [18, 29, 31]. Most important findings regarding physiological differentiation of emotions were summarized in excellent reviews on this issue by Cacioppo *et al.* (1993). Serious methodological criticism of models of peripheral specificity and recommendations for experimental designs intended to test existing emotion theories were put forward by Stemmler (1992). Author outlined importance of the situational response specificity and strongly advocated application of multivariate physiological assessment and comparison of configuration of a profiles of variables in different situational contexts [32].

Numerous efforts has been applied to find most reactive autonomic variable or pattern of several autonomic responses associated with basic emotions in different psychophysiological experimental paradigms such as facial expression manipulation, emotional imagery, viewing of affective pictures or films, and listening to affective music [1, 3, 4, 6, 7, 12, 14, 15, 16, 19, 21, 24, 26, 28, 29, 33, 34]. Careful analysis of reactivity of particular ANS measures in emotions induced by these manipulations gives certain advantages to application of electrodermal and cardiorespiratory variables and their patterns in an attempt to distinguish human basic emotions [3, 4, 5, 7, 12, 15, 19, 21, 26, 28]. There exists many arguments for utility of the simultaneous use of HR (as emotional valence sensitive)[7, 12, 19, 21, 31, 36]; SCR (arousal sensitive) [4, 5, 7, 17, 19, 30, 36] and respiration rate (HR modulator) [2,3,13,24] parameters in assessment of ANS mediated responses in affective visual stimulation mode. However HR discrimination is not always sufficiently reproducible, since heart is an example of an end-organ innervated dually by sympathetic and parasympathetic system and output effector (e.g., HR) is influenced by both autonomic inputs [2,5,13]. For further differentiation of the concrete mechanisms of cardiac reactivity to emotional stimulation heart rate variability analysis (HRV) seems more feasible, especially considering increased awareness about role of respiratory sinus arrhythmia relevant to high frequency (HF) component of HRV and its effectiveness to indicate non-invasively parasympathetic cardiac control [2,13].

EEG studies of discrete emotions have found that EEG power from right frontal areas is higher in negative than in positive emotions [5, 8, 9, 10, 11, 18, 27, 31]. Davidson *et al.* (1990) presented emotionally charged film clips to subject and demonstrated that disgust indicates greater right-sided frontal activation during the disgust than during the happiness condition. However, frontal alpha asymmetry has not been found for emotions comparable in terms of withdrawal or approach tendencies. Other studies also indicated that EEG asymmetry vary more as an approach-withdrawal disposition than as a function of discrete emotion [8, 10, 31].

The most important in the studies of emotions by Davidson's group [8-10] is that they were looking and found a reliable EEG marker for affect. Namely, they showed that the EEG index of activation - reduced alpha activity - when recorded from 2 sites, F3 and F4 (left and right frontal areas, respectively) - predicted affective reactions to affective stimuli and also correlated with affective condition. They recorded the difference in alpha energy between right (F4) and left (F3) frontal areas, and on the basis of these results, they hypothesized that in the left frontal lobe is a positive affect or approach system, whereas a negative affect or withdrawal / avoidance system is located in the right frontal lobe [8,10]. The hypothesis that there is a positive affect system in the left frontal alpha cortex and a negative affect system in the right frontal cortex is actually not confirmable in detail by

A-score (e.g., alpha asymmetry index) data; it is only partially supportable [25]. Thus increases or decreases in the A-score say nothing specifically about which side of frontal cortex is primarily involved in the change, nor in which direction, they say only that one of the three possibilities (F4 alpha decrease, F3 alpha increase, or both changes occurs) is correct, as it was emphasized by Rosenfeld (1997). Thus monitoring of alpha power at both sites, and scoring also beta and theta frontal asymmetries might be helpful for better understanding of processes that take place during emotions [10, 23, 27, 31]. As it has often outlined by some authors [25], there are some distinct functional differences between slow (8.0-10.0 *Hz*) and fast (10.0-13.0 *Hz*) sub-bands of classical alpha rhythm (8.0-13.0 *Hz*), and the same is true for beta rhythms and its sub-bands.

According to multivariable assessment approach physiological emotion-specificity and effective discriminator of emotions should not be sought in terms of single variable of physiological system (cardiovascular, respiratory, electrodermal etc.), but more in a profile of responses or in specific response patterns [17, 24, 29, 32].

The aim of this study was to analyze physiological emotion-specificity during affective visual stimulation and also to test capability of recorded ANS and EEG parameters or their patterns to discriminate basic emotions.

Methods

Subjects and procedure.

Forty two college students (20-26 years old) of both genders (men, N=16) participated in the study. After passing psychometric tests, brief introduction to experimental situation and attachment of electrodes subjects were placed in recliner-chair in sound-proof room with dim lights and were instructed to sit with eyes open and watch the screen where pictures had to be presented by Kodak slide-projector. Initial baseline measurements of physiological signals were taken. Then 14 slides for 7 discrete emotions were selected from the International Affective Picture System (IAPS) [20]. The IAPS numbers for pictures used were: happiness (i.e., happiness nurturant) #2340, (#2040), sadness #2800, (#3350) disgust #3140, (#3071), surprise #3170, (#3051), exciting (i.e., happiness erotic) #4460, (#4232) anger #6540,(#9250) fear #3110, (#1300). Physiological data were analyzed for Set 1 where emotions had higher subjective rating scores than in Set 2 (## in parentheses) for each emotion category.

Baseline values were recorded during 30 sec periods, each picture was presented during 60 s long trial. Two sets of slides were presented in counterbalanced order for each subject. Data were calculated for the first 20s of exposure to stimulus (when peak of most ANS and EEG responses occurred) and 30 s long inter-trial resting baselines. Changes of parameters were computed as compared to relevant baseline levels.

Equipment

Physiological signals were acquired by Grass Neurodata Acquisition System, BIOPAC MP100 hardware with AcqKnowledge III (v.3.5) software. Sampling rate for each physiological signal was 512 Hz. Three Ag/AgCl electrodes were fixed for measurement of Lead I electrocardiogram (ECG). Thoratic pneumogram was recorded with strain gauge transducer. Electrodermal activity was recorded with Ag/AgCl electrodes filled with isotonic Unibase-type gel, and used DC (0.5 V) voltage technique to measure skin conductance. EEG was recorded monolarly from frontal areas (F3, F4).

Autonomic variables:

Electrodermal activity. Specific skin

conductance response amplitude (SCR) as an amplitude of the first SCR within 0.2-4.0 s from onset of visual stimulus, skin conductance response magnitude (SCR-M, i.e., sum of all SCR amplitudes in epoch), SCR number (N-SCR).

Cardio-respiratory activity: Heart rate (HR), inter-beat intervals (IBI), HF and LF components and LF/HF ratio of heart rate period variability , and respiration rate (RESP). Inter-beat intervals (IBI) of ECG were resampled at 10 *Hz* basis and analyzed with Fast Fourier Transformation (FFT) to assess heart rate (period) variability (HRV) using Hanning window. Integrals of spectrum in 0.04- 0.14 *Hz* (LF component of HRV) and 0.14-0.40 *Hz* (HF of HRV) band were measured (in ms^2) in baseline and in experimental conditions [2]. HF/LF ratio was calculated to index ANS balance. Normalized HF/LF reactivity index was calculated as (HF/LF condition- HF/LF baseline)/ HF/LF baseline.

Electrocortical activity. EEG spectral power (FFT, Hanning window) was analyzed for frontal sites (F3,F4, monopolarly referred to ipsilateral earlobe) and power was calculated for following frequency bands: delta (0.5-3.9 *Hz*), theta (4.0-7.9 *Hz*), slow alpha (8.0-9.9 *Hz*), fast alpha (10.0-12.9 *Hz*), slow beta (13.0-19.9 *Hz*), fast beta (20.0-30.0 *Hz*). Relative power (RP) of each band was calculated and converted to percents:

$$\text{e.g., theta relative power} = \text{theta power} / \text{total power}$$

Frontal slow alpha asymmetry index (A-score) was calculated as following:

$$\text{Frontal A-score} = \frac{\text{RP slow alpha F4} - \text{RP slow alpha F3}}{\text{RP slow alpha F4} + \text{RP slow alpha F3}}.$$

Other asymmetry scores were calculated in a similar way for theta, fast alpha, slow beta and fast beta. Statistical analysis was performed by SPSS package using t-test for paired samples.

Results

Autonomic responses

Heart rate. HR deceleration response was typical for all pictures, however IBI increased significantly only in surprise (30.99 ms, $t=4.47$, $p<0.001$) and fear (19.45 ms, $t=2.68$, $p<0.05$). Comparison of the surprise with all other emotions demonstrated significant differences except fear, which on its turn yielded significantly higher IBI response than anger. Higher IBI tonic values differentiate IBI levels of surprise vs. disgust, anger and happiness (all $ps<0.05$). Thus surprise demonstrated most obvious IBI responses, both phasic and tonic, while fear only phasic one.

HRV. LF decreased most in exciting (significantly greater decrease than in anger, fear and disgust), while decrease in surprise was more than in fear ($t=2.20, p<0.05$). As a result tonic level of LF in exciting was lower than in anger ($t=-2.04$, $p<0.05$) and marginally less than in happiness ($t=-2.03$, $p=0.05$), while sad had lower LF values than fear ($t=-2,07$, $p<0.05$) and anger ($t=-2.46$, $p<0.05$.). HF response was featured by more decrease in exciting than in disgust (-3.03 ms^2, $p<0.01$) or surprise ($t=-2.00$, $p=0.05$), while tonic HF levels did not differentiate conditions. However HF/LF index of tonic autonomic balance was lower in anger than in sadness (-0.08 ms^2, $t=-2.12$, $p<0.05$).

Respiration rate. Only disgust showed marginal decrease of respiration rate (-0.63 breath/min, significance of change to baseline, $t=-2.02$, $p=0.05$) significantly different from anger response (0.98 breath/min, $t=3.10$, $p<0.05$). Tonic level of RESP was higher in fear and anger as compared to surprise and happiness (all $ps <0.05$).

Electrodermal activity. SCR amplitude was significantly higher in sadness (0.85 μS) than in disgust (0.58 μS, $t=2.55$, $p<0.05$). However disgust demonstrated more tonic electrodermal activation in a form of higher frequency of N-SCR, which differentiate it from fear (t=3.11, p<0.01), and happiness (t=2.37, p<0.05).

Summary of ANS response changes profiles and differentiation of emotions are presented in Table 1. There are shown only autonomic responses that were both significantly different from baseline and the same time different from any other emotion.

Electrocortical responses

Theta. Negative emotions such as sadness, disgust and fear were featured by significant increase of theta RP both at left and right sides (F3 and F4). Theta response at F3 differentiated disgust-anger (t=2.10, p<0.05), disgust-happiness (t=2.39, p<0.023), and sadness-exciting (t=2.58, p<0.05); as well as fear-anger (t=2.32, p<0.05), fear-exciting (t=2.91, p<0.01), and fear-happiness pairs (t=2.31, p<0.05). The same time at F4 theta response differentiated sadness-anger (t=2.60, p<0.05) sadness-exciting (t=4.26, p<0.001) and sadness-happiness (t=2.08, p<0.05). More details of differentiation by theta power are presented in Table 2.

Slow alpha. All conditions were accompanied by significant slow alpha decrease (F3 and F4). Most pronounced alpha-blocking effects were expressed in exciting (F3) and happiness (F4). Slow alpha decrease in exciting condition was significantly different from sad (F3, t=-3.56, p<0.001; F4, t=-2.02, p=0.05), disgust (F3 only, t=-2.04, p<0.05) and anger (F3, t=-2.39, p<0.05), while happiness was different from sadness (F3, t=-3.06, p<.001; F4, t=-2.47, p< 0.05), and disgust (F4, t=-2.46, p<0.05). Another pair showing differences was sadness-fear (t=3.56, p<0.01), thus denoting that slow alpha manifested least decrement of power in sadness condition.

Fast alpha. Fast alpha blocking was significant in all conditions at both sites (F3, F4), however differentiation happened to be significant only at F3 site (Table 2). Tendencies were similar to slow alpha, namely most profound decrease in exciting and happiness, as well as less reactivity in sadness, fear or anger. Exciting pictures evoked significantly more fast alpha blocking than sadness (t=2.46, p<0.05), and fear (t=2.26, p<0.05), while happiness more fast alpha decrease than sadness (t=2.71, p<0.05), and anger (t=2.07, p<0.05).

Slow beta. IAPS stimulation elicited slow beta response in a form of significant increase from baseline level only in sadness (F3, p=0.05), fear (F3, p<0.01) and exciting (F3, F4, p<0.01). Meanwhile all other slow beta responses were not significant. At F3 exciting slide evoked more slow beta increase than disgust (t=2.28, p<0.05), anger (t=2.22, p<0.05) or happiness (t-2.14, p<0.05), while fear more than disgust (t=2.39, p<0.05), whereas responses at right side (F4) did not differentiate conditions at all.

Fast beta. Frontal fast beta increased in all conditions except sadness (F3,F4, ps=0.052) and disgust (F3, p>0.05), most significantly in surprise (F3, F4). Increase of fast beta in surprise was significantly higher than in sadness (F3, t=2.22, p<0.05; F4, t=2.31, p<0.05), and marginally higher than in disgust (F3 only, t=2.04, p=0.05). Fear also demonstrated relatively high fast beta response, but it only tended to differentiate from disgust (F3, t=2.02, p=0.052).

Frontal asymmetry

Frontal theta asymmetry. Positive tonic theta asymmetry was significant only in sadness condition (0.03, t=2.87, p<0.01). Theta asymmetry in sadness was significantly different from anger (t=2.46, p<0.05), exciting (t=2.48, p<0.05), and disgust (t=2.34, p<0.05). Table 3 shows frontal asymmetry indices for all EEG bands.

Frontal alpha asymmetry. Slow alpha asymmetry was significant and positive only

Table 1. ANS responses magnitude profiles of emotions

	Autonomic responses					
Emotions	N-SCR	SCR	IBI (20s)	LF	HF	RESP
ANGER						
DISGUST	increase [f,h]					decrease[a]
EXCITING				decrease[a,d,f]	decrease[d,sr]	
FEAR			increase[a]			
HAPPINESS						
SADNESS		increase[d]				
SURPRISE			increase[a,d,e,h,s]			

Autonomic responses are shown only if 1) they change significantly vs. baseline; 2) they differentiate vs. any other emotion. Abbreviations of emotions (in upper line): *a*-anger, *d*-disgust, e-exciting, *f*-fear, *h*-happiness, *s*-sadness, *sr*-surprise.

Table 2. EEG responses profiles of particular emotions and differentiation summary.

	EEG band and site of recording							
Emotion	THF3	THF4	SAF3	SAF4	FAF3	SBF3	FBF3	FBF4
ANGER			decrease[e]		decrease[h]			
DISGUST	increase[a,h]	**increase**[a,h]	decrease[e]	decrease[h,s]				
EXCITING			**decrease**[d]	decrease[e]	decrease[s,f]	**increase**[a,d,h]		
FEAR	**increase**[a,d,e]	increase[a,e]			decrease[e]	increase[d]	increase[d]	
HAPPINESS			decrease[s]	**decrease**[d]	**decrease**[a,s]			
SADNESS	increase[e]	increase[a,e,h]	decrease[e,f,h,sr]	decrease[e,h]	decrease[e,h]			
SURPRISE			decrease[s]				**increase**[d,s]	**increase**[s]

Presented are only significant changes of relative power from baseline that differentiate from any other emotion. Bold outlines highest magnitude of response for each EEG band. Fast alpha (F4) and slow beta (F4) do not differentiate any emotions and are not shown. Abbreviations of EEG bands: TH-*theta*, SA-*slow alpha*, FA-*fast alpha*, SB-*slow beta*, FB-*fast beta*. Abbreviations of emotions (in upper line) in pair-wise comparisons: *a*-anger, *d*-disgust, e-exciting, *f*-fear, *h*-happiness, *s*-sadness, *sr*-surprise.

Table 3. EEG frontal asymmetries profiles in IAPS elicited emotions (tonic asymmetries).

	Frontal asymmetry index				
Emotions	Theta	Slow alpha	Fast alpha	Slow beta	Fast beta
ANGER					negative
DISGUST					
EXCITING		positive[s,sr]	positive[f,sr]	negative[d]	
FEAR			negative[e]	negative[d]	
HAPPINESS					negative
SADNESS	positive[a,e,d]				negative
SURPRISE					

Asymmetry index was calculated as (F4-F3)/(F4+F3) for each frontal rhythm. Positive index indicates more relative power of particular rhythm in the right frontal area, whereas negative index - in the left frontal area. There are shown only asymmetries significantly different from zero. Results of pairwise comparison by t-test for significant differences between emotions are shown by upper case letters. Abbreviations: a-anger, d-disgust, f-fear, e-exciting, h-happiness, s-sadness, sr-surprise. *Note*: Fast beta did not differentiate emotions, but was significantly negative in approach tendency emotions (anger, happiness and sadness).

in fear (0.04, t=4.26, p<0.001) and exciting (0.04, t=3.63, P<0.01) conditions. Sadness had significantly lower slow alpha asymmetry than exciting (t=- 2.16, p<0.05), while surprise lower asymmetry than both fear (t=-2.10, p<0.05) and exciting (t=-2.10, p<0.05). Fast alpha asymmetry was significantly positive in exciting condition only (0.03, t=2.16, p<0.05), statistically different from surprise (t=2.16, p<0.05), and fear (t=2.41, p<0.05). As a matter of fact, fear was the only one emotion where fast alpha asymmetry significantly decreased from baseline (-0.02, t=-2.17, p<0.05).

Frontal beta asymmetry. Negative values of slow beta asymmetry were typical for all conditions except disgust, however only fear demonstrated significant negative value of asymmetry (-0.02, t=-3.67, p<0.01), significantly different from disgust (t=2.89, p<0.01). Also exciting (i.e., erotic) condition was different from disgust (t=-2.06, p<0.05), the latter was the only one where asymmetry tended to be positive (p=0.056). Fast beta was significantly negative in anger, happiness and sadness, but did not differentiate conditions (Table 3).

DISCUSSION

General profile of responses

Most typical responses in all conditions were IBI increase, decrease of LF and HF components of HRV, electrodermal activity in a form of specific SCR and increased frequency of nonspecific N-SCR activity, tendency to RESP decrease, and EEG changes expressed in theta increase (sadness, fear), alpha blocking (both slow and fast alpha sub-bands) and increased beta activity (slow and fast beta), positive values of alpha asymmetry and negative of beta asymmetry. However particular emotions demonstrated variations of response profiles.

To summarize ANS and EEG response profiles specifics of emotions elicited by IAPS (see Tables 1-3) the following description could be presented:

Surprise: IBI increase in surprise came without detectable changes in HF or LF or their balance and were not accompanied by increased electrodermal and respiratory activity. Surprise was featured by significant bilateral theta increase, left slow alpha decrease (resulted in slow alpha asymmetry), and significant fast beta increase. Thus only HR deceleration and bilateral fast beta increase differentiate this emotion reliably.

Disgust: Conversely, disgust was characterized by modest IBI changes without significant shifts in HF and LF levels, but demonstrated tonic electrodermal activation (high N-SCR frequency with low SCR amplitudes) and decreased RESP. Disgust did not demonstrate any shifts in alpha and beta activity nor in alpha and beta asymmetry. However disgust was marked by more theta activity, especially at right side which was not nevertheless associated with theta asymmetry.

Exciting (erotic): Excitement expressed least IBI changes, accompanied by simultaneous LF and HF decrease, that however did not affect HF/LF ratio. Exciting condition demonstrated no much theta changes, but significant alpha changes with high right asymmetry of slow and fast alpha associated with significant left slow beta changes and negative slow beta asymmetry.

Sadness: Sadness resulted in highest amplitude of specific SCR among all conditions, highest level of HF/LF balance, but modest cardiac chronotropic responses and low respiration rate. Sadness was exceptional in terms of obvious right theta increase and positive theta asymmetry index, but with small changes in alpha and beta bands. An exception was only negative fast beta asymmetry index, without differentiation from any other emotions.

Anger: ANS responses in anger were featured by high RESP, small IBI changes, high level of LF components of HRV and low values of HF/LF ratio. Anger did not demonstrate marked shifts in alpha and beta activity, nor alpha and beta asymmetries, except for fast beta asymmetry and unilateral alpha blocking (F3).

Happiness: Autonomic changes in happiness were quite similar to those observed in anger, i.e., low electrodermal activity, small chronotropic responses, high LF component of HPV, however RESP was low. Happiness was mostly characterized by significant bilateral alpha reactivity (alpha power decrease) without any changes in theta and beta.

Fear: Fear demonstrated significant increase in IBI, high LF level and high RESP. EEG profile of fear was expressed in theta increase, more pronounced left side, changes of fast alpha , as well as slow and fast beta (F3) which led to profound negative slow beta asymmetry (significantly different from disgust).

Differentiation of emotions by physiological profiles

As we can see in Tables 1-3 most differences were found for exciting as emotion (both ANS and EEG, as well as EEG only) and surprise (ANS only). Most different pairs were exciting-surprise, exciting-sadness and exciting -fear. Least number of differences was typical for happiness, nevertheless happiness-sadness and happiness-disgust pairs had considerable number of EEG differences, especially in alpha and theta sub-bands.

Peripheral physiological emotion specificity concept and experimental design intended to discriminate particular physiological responses during different emotional states depends both on adopted theory of emotion and model of specificity as it was quoted by Stemmler (1992). Most important and still unresolved issue was how to link conceptually EEG, brain hemispheric asymmetry and autonomic parameters (HR, HRV, EDA, respiration) with such psychological process as emotion. An indicative qualities of particular physiological variables [4] might be rather valuable tools to understand functional significance of observed integrated responses.

Frontal theta changes are characteristic of vigilance and other tasks involving attention [23]. The theta band also have to be taken into consideration in emotion research, because while in some tasks and conditions, theta activity appears to be dissociated from alpha, for example in our study in disgust and sadness emotions. Also like alpha asymmetry, theta asymmetry appears to reflect hemispheric task demands. Our results demonstrate significantly higher frontal theta asymmetry in sadness as compared to anger, exciting and disgust.

Left frontal activation therefore is considered to be related more to behavioral activation system [8-11, 27, 31]. The approach/withdrawal motivational model of emotion and frontal brain asymmetries suggests that approach emotions such as happiness and anger are associated with relatively greater left frontal brain activity, whereas withdrawal emotions such as sadness, fear, and disgust are associated with relatively lower left frontal brain activity [5, 10]. Our data only partially match this assumptions.

Right hemisphere activation specific for negative emotion processing [10, 31] and enhanced fast beta in right frontal areas along with negative frontal asymmetry indices showed tendency for right hemisphere dominance in fear, and left hemisphere dominance in excitement (erotic). Our data support suggestion that right hemisphere might be preferentially involved also in generation of both sympathetically (SCR, N-SCR, LF of HRV) and parasympathetically (HR, HF of HRV) mediated responses during emotionally negative states (fear) and states featured by strong orienting (surprise). The results are compatible with findings on peripheral autonomic control of cardiac activity that chronotropic cardiac activity (HR) is predominantly and more effectively controlled by sympathetic and parasympathetic ipsilateral pathways running on the right side [18, 35]. Lateralization of brain functions in autonomic control during affective states as an approach conceptually linking brain frontal asymmetry, autonomic arousal and emotions seems rather perspective one [29, 31] and deserves more experimental studies.

Conclusion

Physiological responses during 20 s of exposure to IAPS slides intended to elicit happiness (nurturant and erotic), sadness, disgust, surprise, fear or anger emotions were quite similar and were expressed in heart rate (HR) deceleration, decreased HR variability (HRV), specific SCR, increased non-specific SCR frequency (N-SCR), and EEG changes exhibited in theta increase, alpha-blocking, increased beta activity, and frontal asymmetry. However, particular emotions demonstrated variations of the response profiles, enabling to differentiate some pairs of emotions by several physiological variables. The profiles showed higher magnitudes of HRV and EEG responses in excitement (e.g., erotic) and higher cardiac and respiratory responses in surprise. The most different pairs were exciting-surprise (by HR, HRV, theta, alpha asymmetry), exciting-sadness (by theta, alpha and alpha asymmetry) and exciting-fear (by HRV, theta, F3 alpha, alpha asymmetry), or in other words examples of positive-negative pairs. Happiness yielded the least differentiation. Differences were found as well within negative emotions, e.g., anger-sadness were differentiated by HRV and theta asymmetry, while disgust-fear by N-SCR frequency and beta asymmetry. Obtained results suggest that magnitudes of profiles of physiological variables differentiate emotions evoked by affective pictures, despite the fact that the patterns of most responses were featured by qualitative similarity in given passive viewing context. Further progress in identification of emotion-specific physiological profiles and principles of differentiation of emotions by their responses patterns should be sought in theoretical foundations linking brain functional asymmetry and autonomic arousal control specificity in emotions.

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