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The Effects of Habituation and Sensitization on Psychophysiological Differentiation of Responses to Auditory Stimulation with Automobile Horns*

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Abstract. Psychoacoustic characteristics of automobile horns play significant role in resulting subjective evaluation and psychophysiological reactions. However, comparison and differentiation of physiological responses to commercially available horns is a complicated task due to the small contrast in technical features of horns and the influence of such processes as habituation on physiological outcome with the increased number of auditory stimulation trials. In a study on 10 college students, there was performed comparative analysis of reactivity of physiological responses mediated by central and autonomic nervous systems in order to identify the role of habituation on decrement of psychophysiological responsivity and assess the ability to differentiate subjectively most and least preferred, as well as most and least appropriate horns according to physiological manifestations. The EEG and autonomic responses to 7 automobile horns were analyzed during 3 blocks of trials, with varying order of stimuli and changed acoustic parameters of horns in each block. Thus, responses were analyzed for totally 21 trials of auditory stimulation. It was shown that electrodermal and cardiovascular responses have different reactivity patterns to repeated stimulation: skin conductance measures habituated, cardiac reactivity showed no signs of habituation, and the vascular response demonstrated sensitization. The temporal EEG exhibited marked habituation of fast beta band power, while alpha-blocking effect did not habituate during the course of experiment. Differentiation of physiological responses of most and least preferred and appropriate horns was possible in our study, however, some cardiovascular reactivity measures differentiated during the entire course of the experiment, while EEG and electrodermal parameters showed significant differences only during first block of trials, and were later affected by the habituation.

Introduction

Engel (1960) was one of the first researchers to understand the utility of an automobile horn as a laboratory stressor by studying its physiological effects in order to identify stimulus-response specificity.

Actually, an automobile horn's psychoacoustic characteristics (intensity, loudness, sharpness, tonality, roughness etc.), as well as vital significance (signal of danger,

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alarm etc.) and subjective aversiveness (unpleasantness, negative emotional valence etc.) make it a valuable naturalistic auditory stimulus for psychophysiological research. However, comparison of commercially available car horns in a laboratory setting is a complicated task for several reasons: 1) relative similarity of the technical (psychophysical) characteristics of high quality competitive brand-name horns produced by different well-known manufacturers (Bosch, Hella, Mixo etc.) makes the contrasts between auditory stimuli quite small and the differences in magnitudes of responses rather hard to detect; 2) the influence of psychophysiological processes such as the habituation and adaptation on the physiological responses when horns are used as acoustic probes in the repeated stimulation design; 3) · the reduction of the amount of psychophysiological reactivity on physiological and subjective levels with an increased number of exposures to intense auditory stimuli due to habituation.

An intense startling auditory stimulus invariantly evokes physiological reaction, that is orienting response (OR) [2-4, 17]. However, the habituation always occurs with the repeated presentation of the same stimulus or relatively similar stimuli of the same sensory modality, for instance, such as the automobile horns produced by different companies [4-5, 10, 19]. After the habituation process, nevertheless, the orienting response re-installment follows changes in stimulus parameters, namely, intensity, modality, duration, frequency, sequence, complexity and significance [5-7, 17]. This means that dishabituation (i.e., OR re-installment) may also be elicited by changes in frequency components of acoustic probe within the same sensory stimulus modality [15-16,19]. The role of stimulus significance and novelty has been discussed in detail in psychophysiological literature, since for a certain period of time it was a topic of an intense debate [2-4, 9, 12, 16-17, 21].

Role of the orienting response should be decribed in more details for better understanding of physiological reactivity to intensive auditory stimulation, especially when stimulus posses vital significance of danger. The orienting response is comprised of the following typical psychophysiological pattern: increased sensitivity of the sensoty systems, dilation of cerebral and constriction of peripheral vessels, deceleration-acceleration wave in heart rate (HR), increase skin conductance level (SCL) with pronounced skin conductance response (SCR) with 0.5-4.0 sec onset latency, increased beta power and alpha-blocking in the EEG [2-4,6,10,17,19]. The orienting reflex enables to attend to novel stimulus and thus facilitates an adaptive response to it, but once the stimuli poses no more real threat, the OR habituates [1,4,6].

Autonomic measures are widely used in research of processes related to the OR and habituation. Among the physiological indicators of habituation, SCR is the most frequently used one, and is evidenced by decreased amplitude over trials. Peripheral vasomotor parameters (i.e., finger pulse volume decrease) are also popular measures along with other cardiovascular ones, as well as electrocortical parameters such as alpha and beta rhythms spectral power of the EEG [5-6, 10, 15-17].

Taking into account that physiological responses evoked by horn stimulation might become lower with increased number of the trials due to expected habituation effects, experimental design with counterbalanced order of stimuli presentation was not appropriate in this study. The better approach would consist in the entering variability in the stimuli characteristics (e.g., varying frequency components of horns) to ensure re-installment of the OR by introducing novelty and thus try to lower effects of habituation. Though this design cannot eliminate habituation effects it allows to control the influence of the adaptation process on most habituation phrone measures.

The current study used comparative analysis of physiological responses evoked by startling auditory stimulation with the various automobile horn as an acoustic probe. The goals included the identification of the central and autonomic reactivity to horn probe; investigation of the habituation course of the EEG, electrodermal and cardiovascular responses; as well as to differentiate physiological response patterns to horn pairs subjectively evaluated as the most and the least preferred, appropriate, and arousing.

The main aim of the study was assessment of the effects of habituation on ability to distinguish physiological responses to automobile horns of different subjective preference.

Methods

Ten college students (19-23 years old) participated in this study. Physiological signals (EEG, electrocardiogram, finger photoplethysmogram (PPG), skin conductance, and pneumogram were recorded by BIOPAC 100WS, Grass Neurodata System and AcqKnowledge III (v.3.5) software. The following EEG and autonomic variables were measured for each condition: relative power (RP in percents from total power) of alpha and beta bands in the EEG spectrum (T3, T4, F3, F4, O1, O2), heart rate (HR), respiratory sinus arrhythmia index (RSA, calculated as difference between minimum and maximum HR in each respiration cycle)[11], pulse transit time (PTT, time delay between R-wave of ECG and relevant maximum of pulse wave in PPG in the same cardiac cycle - inversely related to mean beat-to-beat blood pressur)[14], finger pulse volume amplitude (PV), skin conductance level (SCL), skin conductance response (SCR) amplitude and rise time, number of SCRs [3]. Pneumogram was used during raw data processing for accurate estimation of the RSA variable. After preliminary screening of the raw EEG data, the analysis was limited to estimation of RP of slow alpha (8.0-9.99 Hz) and fast beta (20.0-30.0 Hz) at temporal sites of the EEG recording (T3 and T4, monopolar) as the most reactive and representative electrocortical measures. Only these EEG data are reported in the study.

The procedure consisted of adaptation to laboratory situation and 3 blocks of experimental sessions. Each session comprised of 20 sec recording of resting baseline and trials of 5 sec long stimulation by automobile horn. In the first session 7 various horns were used ("mixed" mode, e.g., both high and low frequency bands were included, hereafter referred to as the mixed mode). In the second sessions the same 7 horns were used, but in different order and only with high frequency components of horn (high mode), while in the third session the same 7 horns werepresented in a new order but with only low frequency bands (low mode). After each stimulation trial, subjects were requested to fill in paper question- naires regarding subjective rating of appropriateness, preference and arousalabilty of the delivered horn stimuli. Technical characteristics of employed horns are presented in Table 1. Details on psychometric questionnaires and in-depth description of the psychoacoustic characteristics of the automobile honks used in this study were reported elsewhere in [20].

Table 1. Technical and psychoacoustic characteristics of automobile horns employed in the study. characteristics of automobile horns employed in the study.

Products	spectrum (dB)	loudness (sone/Bark)	sharpness (acum)	roughness (asper/Bark)	tonality (tu)
Hella/100phi/shell/ Germany	109.5	205.63	8.77	3.27	0.78
Mixo/100phi/shell/ France	110.00	202.69	8.32	3.33	0.82
Grandeur/100phi/ shell/Korea	101.05	120.24	5.19	2.2	0.84
Hella/100phi/ flat/Germany	118.25	368.44	22.87	5.91	0.56
Bosch/100phi/ flat/Spain	112.95	250.86	15.08	3.45	0.76
Sonata/100phi/ flat/Korea	103.10	142.91	11.17	0.22	0.88
Knight Horn/ 100phi/flat/Japan	116.9	272.36	15.06	2.23	0.66

Additional information on psychometry (i.e., appropriateness, preference and arousalability rating scales) are available from corrsponding author upon request. Statistical analysis was performed with SPSS package (v. 8.0) using linear regression curve estimation method, ANOVA, t-test for paired samples and Pearson correlation.

Results

ANS reactivity trends. The ANS responsivity to stimulation with increasing number of trials was analyzed by linear curve regression estimation method to demonstrate habituation and decrement of reactivity with repeated stimulation. Multiple linear regression coefficient (r and standard error, SE) were calculated for each dependent variable (HR, RSA, PTT, PV, SCL, N-SCR and slow alpha and fast beta RP changes from baseline during stimulation) plotted across auditory stimulation trials (N of trials was independent variable). Significance of multiple regression coefficient was estimated by ANOVA. Regression coefficient was assumed as significant if $p<0.05$.

Electrodermal activity was found to be most habituation prone since all skin conductance variables exhibited profound linear decrement trends. SCL decrease was linear with $r=-0.75$, $SE=0.52$, ($F=8.50$, $df=1,19$ $p<0.01$). SCR amplitude with $r=-0.45$ ($SE=0.48$, $F=5.03$, $df=1,19$, $p<0.05$), as well as the most dramatically reduced SCR rise time ($r=-0.81$, $SE=0.25$, $F=37.75$, $df=1,19$, $p<0.01$), and percentage of scorable (minimal SCR scoring criteria was set as 0.05 uS) SCRs to stimulation ($r=-0.84$, $SE=0.80$, $F=47.04$, $df=1,19$ $p<0.01$). Conversely, cardiovascular variables did not manifest decrement of reactivity and remained reactive all over the trials. Namely, PTT and RSA did not showed any drift of reactivity. HR responses tended to be slightly enhanced with an increased number of trials, while PV responses (i.e., PV decrease, or vasoconstriction) were significantly facilitated with repeated stimulation (r=-0.68, SE=0.35, F=13.19, df=1,19, p<0.01). Thus, no signs of cardiovascular habituation was detected. Furthermore, vascular components of cardiovascular response (e.g., pulse volume decrease) showed a sensitization tendency. Figure 1a demonstrates trends of standardized SCL, PV, and PTT across the horn stimulation trials. Standardization was proceeded by converting changes of parameters from baseline to percentage values.

(T3,T4) demonstrated concurrent reactivity trends for relative powers of slow alpha (sensitization) and fast beta (habituation). Reactivity of slow alpha tended to increase over auditory stimulation trials, namely for standardized slow alpha at T3 it was significant (r=0.47, F=5.51, p<0.05), while for T4 it showed tendency to increment (r=0.40, F=3.74, p=0.06). In contrast, fast beta power reactivity decreased both at T3 (r=-0.63, SE=0.64, F=12.91, p<0.01), and T4 (r=-0.49, F=6.16, p<0.05). These data are shown on Figure 1b. The trends of tonic EEG levels of analyzed bands had similar tendencies: increase of slow alpha RP (T3, r=0.68, F=16.85, p<0.01; T4, r=0.74, F=23.18, p<0.01) and decrease of fast beta RP in the EEG (T3, r=-0.73, F=22.28, p<0.01; T4, r=-0.71, F=19.71,p<0.01).

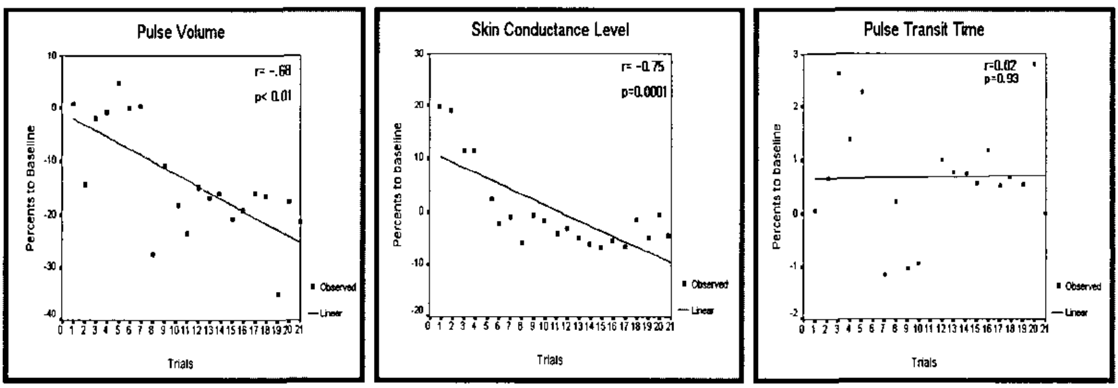


Figure 1a. Regression analysis of standardized SCL change, finger pulse volume (PV) and pulse transit time (PTT) over trials of auditory stimulation with automobile horns. SCL endures marked habituation (r= 0.75, p<0.01), while pulse volume decrease response(vasoconstriction) demonstrates facilitation of reactivity (r= 0.69, p<0.01). PTT does not habituate, nor sensitize. X axis : number of trials. Y axis : changes from baseline(%), N=10.

EEG reactivity trends. The temporal EEG

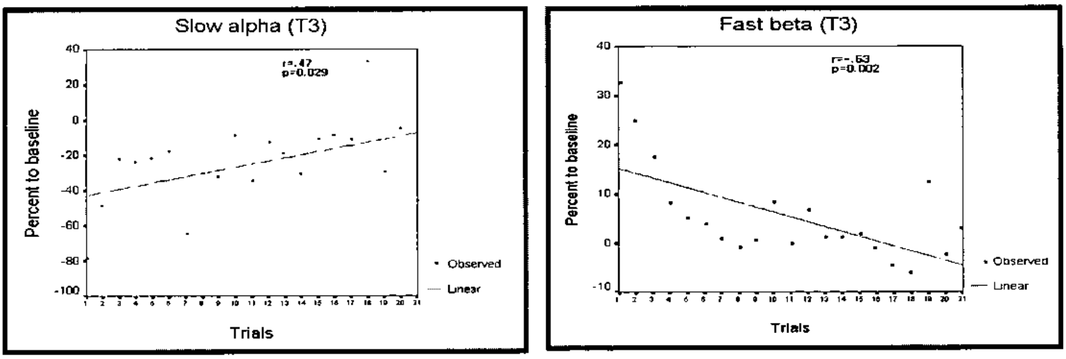


Figure 1b. Regression analysis of standardized slow alpha (F3) and fast beta (T3) RP responses over trials of stimulation with automobile horns. Slow alpha responses demonstrate sensitization, while fast beta shows habituation. Linear regression trends are significant statistically.
X axis : number of trials, Y axis : changes from baseline(%), N=10.

Differentiation of subjectively different horns by physiological responses. Differentiation of physiological responses within subjective rating categories was performed with paired sample t-test. Analysis of differences among physiological responses with relevance to subjective ratings data showed that in preference category the most preferred horn (Hella/100phi/shell, Germany) evoked cardiac and electrodermal responses distinct from the least preferred horn (Knight horn/100phi/flat, Japan).
However, electrodermal differentiation was significant (e.g., tonic SCL higher in preferred on 2.54 uS, $p < 0.05$), or close to significance level (phasic SCL, $p=0.059$, SCR amplitude higher in preferred on 1.39 uS, $p=0.06$), but only in the first session (mixed horns), while both phasic HR and tonic RSA differentiation were still valid in high and low sessions (e.g., HR accelerated on 3.86 bpm more to Hella than to Knight horn, $p<0.05$; while RSA was on 1.42 bpm lower, $p<0.05$). Fast beta power (T3) decreased more when reacting to the least preferred horn in the mixed session. In the most-least preferred pair, phasic RP change of fast beta difference was significant ($p<0.05$). Tonic levels of fast beta and slow alpha (T3) were also significantly different ($p<0.05$) between the most and the least preferred horns in the same session.

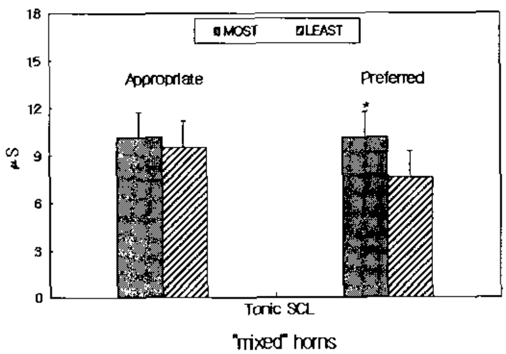
Differentiation of physiological responses according to subjective appropriateness rating was significant only in the mixed session for the most (Hella/100phi/shell, Germany) and the least appropriate horn (Grandeur/100phi/shell, Korea) pairs. In particular, observed electrodermal activity demonstrated that phasic SCL increase was higher for the most preferred horn (0.64 uS, $p<0.05$), with trends toward higher SCR amplitude ($p=0.057$) and higher basal SCL ($p=0.07$), while both tonic RSA level and RSA decrease were significantly more reactive to the most appropriate horn. Fast beta RP tonic level (T3) was higher to most appropriate as compared to the least appropriate horn ($p<0.05$), while slow alpha RP for the most appropriate horn was marginally lower ($p=0.05$) in the mixed session. The same time tonic slow alpha level (T3) was lower during exposure to the most appropriate horn ($p<0.01$) in the same session.

Differentiation by arousalability rating yielded significantly lower tonic HR (Knight/100phi/flat, Japan, most arousing) only during the low session, as compared to the least arousing horn, (Mixo/100phi/shell, France) and less HR acceleration as a result of exposure to most arousing horn in the high session (Knight / 100phi / flat, Japan vs. Hella / 100phi / shell). However, fast beta power (T3,T4) was lower for the most appropriate horn during the mixed session (change scores from baseline -3.41 and -3.44 respectively, $ps<0.05$), while slow alpha power (T3) was higher ($p<0.05$) in the high session. The low session did not show any EEG differentiation.

Thus, physiological response differentiation by appropriateness and preference rating was effective in mixed conditions for both autonomic (SCL, HR, RSA) and EEG measures, while in high and low conditions only HR, RSA, and slow alpha showed significant of differences in the most vs. the least preferred, appropriate, or arousing horns. The EEG differentiation was significant only for mixed, and in the only one case during the high session, while it failed to show any difference of responses during low session. Some differentiation results are presented on Figures 2-4.

Habituation of subjective rating scores. Regression analysis demonstrated an unchanged preference rating with the increased number of trials (linear trend $r=-0.02$, $SE=0.23$, $F=0.05$, $p=0.99$), as well as practically unchanged appropriateness rating scores. Whereas, arousing rating scores demonstrated only a tendency to incline ($r=0.31$, $F=2.15$, $p>0.05$), featuring a slight incremental increase of arousing qualities of stimulation by the end of the experimental sessions.

a



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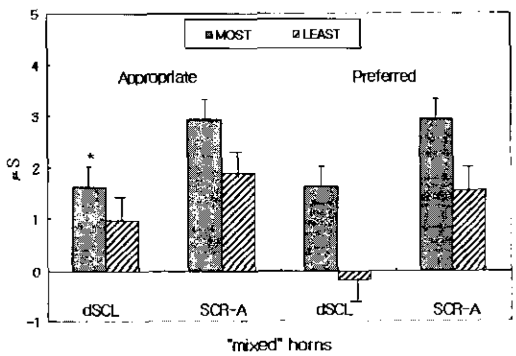

Figure 2. Differentiation of electrodermal responses (Means with SE) to the most and least appropriate and preferred horns in the first ("mixed") stimulation session. Fig. 2.a. shows differences of basal (tonic) SCL, while Fig. 2.b. differences of phasic SCL changes (dSCL) and SCR amplitudes. Asterisks show significance of differences by t-test: * $p<0.05$

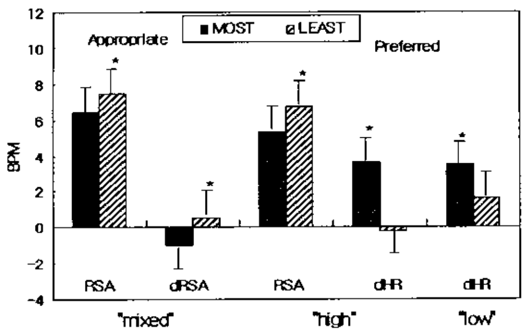

Figure 3. Differentiation of phasic (dHR, dRSA) and tonic (RSA) cardiac responses to the most and the least subjectively appropriate and preferred horns in the first ("mixed"), the second ("high"), and the third ("low") sessions of auditory stimulation. Mean values are presented with SE (N=10). Significant differences by paired sample t-test are marked by asterisks. *$p<0.05$

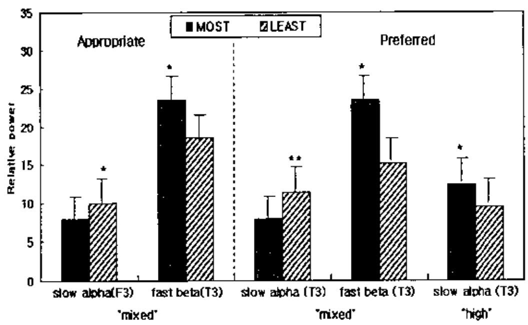

Figure 4. Differentiation of tonic slow alpha and fast beta responses (T3) to the most and the least subjectively appropriate and preferred horns in the first ("mixed") and the second ("high") session of auditory stimulation with horns. Mean with SE (N=10), paired sample t-test: *$p<0.05$, **$p<0.01$

Correlation analysis of physiological variables and subjective rating scores.

The positive correlation among subjective rating scores was significant only for appropriateness-arousal pair (Pearson correlation $r=0.67$, $p<0.01$). Preference rating did not correlate with any of physiological responses, while arousal scores positively correlated with HR acceleration ($r=0.49$, $p<0.05$), and negatively with PV ($r=-0.44$, $p<0.05$), SCL ($r=-0.45$, $p<0.05$) and SCR amplitude ($r=-0.44$, $p<0.05$). Subjective rating scores did not show correlation with any of the EEG parameters.

Discussion

Patterns of habituation of autonomic variables. Skin conductance response decrement was observed over experimental trials, and this result is compatible with the reports on the habituation of SCR during repeated trials in most of the studies of the electrodermal reactivity to sudden loud stimuli [4, 6, 13]. Electrodermal activity in our study habituated and matches these data, whereas cardiovascular activities failed to habituate. Tonic cardiac activity (HR, RSA) was facilitated, as well as phasic vascular responses (PV), and we suggest manifestation of cardiovascular sensitization [12, 20], or in other words the process of dishabituation of cardiac and vascular activities [7, 19].

There is extensive literature documenting HR acceleration following intense noise stimulation (85-110 dB) [19]. The observed pattern of HR increment has been reported elsewhere with respect to less intensive (80-100 dB) but longer (duration more than 5 sec) bursts of white noise [10]. The important finding is that the ANS responses to startling auditory stimulation have each their own unique pattern of changes in response to repetitive stimulation. The concurrence of skin conductance response habituation and tonic HR increase may be understood in the context of the dual-process theory of habituation [12, 18, 20]. In dual-process theory proposed by Groves and Thompson (1970) and Thompson et al. (1979), two independent processes of habituation and sensitization occur in response to repetitive stimulation. Habituation influences the stimulus-response type and is a decremental process, while sensitization influences the reactivity state of the subject and is an incremental process [12, 21]. States refers to the tonic level of excitation or activation elicited by the recurrent stimulation, with "arousal serving the role of sensitization of state" [12, p. 52] In our study only electrodermal activity showed decrement of responses and marked habituation, while vascular reactivity was facilitated and overall cardiovascular activity (HR, RSA, PTT), that presumably reflects tonic state, failed to show habituation. The distinctive facilitation of cardiovascular activity indexes the sensitization process [18], which is related to induced tonic arousal, suggesting that the repetitive startling stimulation with horns is stressful [13]. This notion is supported also by the positive, yet non-significant, trend of the arousalability rating scores found in our study.

EEG habituation patterns. Phasic and tonic RP of temporal (T3,T4) slow alpha did not show habituation across 3 sessions with a total of 21 trials of auditory stimulation Alpha-blocking effect was persistent during whole experiment and this result is in accord with data reported by [5,18]. The relative power of fast beta (T3,T4), on the other hand, demonstrated marked habituation of both phasic reactivity and tonic levels. Decrement of the beta power reactivity indicates a decrease of orienting significance of stimuli with repeated presentation [1], but at the same time is independent from reactivity of the slow alpha band which turned out to be more sensitive to variations in the entire acoustic stimulus properties. The same time changes in alpha power may indicate fluctuations of arousal level during the experiment and thus reflect the state (or tonic activation) according to the dual-process theory of habituation [12,18, 21].

Conclusions

Auditory stimulation with automobile horns evoked autonomic responses in the form of HR acceleration, RSA decrease, finger pulse volume decrease, moderate PTT increase, and electrodermal activity expressed in an increase of SCL and SCR of high amplitude, as well as slow-alpha blocking effect and increase of fast beta activity in the temporal EEG. As the number of the trials increased with repetitive stimulation with 7 different horns in 3 sessions with varying complexity of auditory stimuli there occurred habituation of electrodermal responses and fast beta reactivity, but habituation of alpha-blocking failed to appear, as well as an adaptation of cardiovascular reactivity in general. Furthermore, vascular responsiveness to stimulation was facilitated. The concurrent course of habituation of electrodermal and cardiovascular activity can be explained by sensitization of vascular responses typical for defensive or orienting reactions elicited by intensive auditory stimulus. In the first session of auditory stimulation it was possible to differentiate subjectively most and least preferred and appropriate horns by their electrodermal (SCL, SCR amplitude), cardiovascular (RSA, HR) and EEG (slow alpha, fast beta power) responses. However, in repeated sessions of stimulation with modified frequency components of presented horns, differentiation was possible only by phasic and tonic cardiac activity (HR and RSA) and alpha-blocking responses, due to strong habituation effects on electrodermal reactivity and fast beta responsiveness. The potential implications of this results emphasize importance of both subjective and physiological measures in an adequate assessment of the functional appropriateness of such product as automobile horn. At the same time our data stress importance of the selection of physiological measures (cardiovascular parameters and alpha rather than electrodermal parameters and beta in the EEG) less vulnerable to habituation in experiments with repeated stimulation with intense auditory probe. The results can contribute to the design and production of automobile horns with proper impact on traffic participants (drivers, pedestrians) and environments.

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