COMPARATIVE ANALYSIS OF PSYCHOPHYSIOLOGICAL REACTIVITY TO AUDITORY STIMULATION WITH AUTOMOBILE HORNS

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Abstract

Automobile horn's psychoacoustic characteristic and significance as a naturalistic signal of danger makes it a valuable auditory stimulus to study such psychophysiological responses as startle, orienting and defense reactions. However, comparison and differentiation of physiological responses to commercially available horns is a complicated task due to small contrast of technical features of horns and influence of such processes as habituation on physiological outcome with increased number of auditory stimulation trials. In the study on 10 college students we performed comparative analysis of tonic and phasic reactivity of physiological responses mediated by autonomic nervous system in order to identify role of habituation and decrement of autonomic responsivity, as well as possibility to differentiate subjectively most and least preferred and subjectively more appropriate horns according to physiological manifestations. It was showed that electrodermal and cardiovascular reactivity have concurrent patterns of adaptation to repeated stimulation, namely skin conductance variables habituated, cardiac reactivity failed to show signs of habituation, while vascular component of response were facilitated demonstrating marked sensitization. Differentiation of physiological responses to horns with respect to their subjective rating scores was possible, however electrodermal reactivity was effective only at the first block of trials , while phasic and tonic cardiovascular reactivity differentiate responses during whole course of experiment. There are discussed possible autonomic mechanisms involved in mediation of observed results.

Introduction

Engel (1960) was one of the first authors to understand utility of automobile horn as a laboratory stressor studying its effects on heart rate (HR), HR variability , blood pressure (BP) and temperature and comparing them with responses to other stressors such as mental arithmetic, cognitive tasks , cold pressor and isometric exercise in order to identify stimulus-response and individual-response specificity. Actually, automobile horn's psychoacoustic characteristics (intensity, loudness etc.) as well as vital significance (signal of danger, alarm etc.) make it a valuable naturalistic auditory stimulus to study such psychophysiological responses as startle, orienting and defense reactions. On other hand, horns evoke subjective responses usually featured by aversiveness to applied stimulation. However, comparison of different commercially available car horns is a complicated task due to several reasons: 1) relative similarity of technical characteristics of high quality competitive brand-name products produced by different well-known manufacturers (i.e., Bosch, Hella etc.) that makes contrasts between auditory stimuli quite small and differences in magnitudes of responses hard to detect; 2) impact of psychophysiological processes such as adaptation and habituation of physiological responses when horns are used as acoustic probes in repeated stimulation design; 3) difficulties in adequate subjective evaluation of horn quality using emotional preference (e.g., a horn which is more pleasant emotionally, on other hand may be evoking less profound physiological arousal , while, on contrary, functionally more alerting horns seems to be more appropriate product); 4) the amount of psychophysiological reactivity should be reduced on physiological and subjective levels with increased number of exposures in laboratory setting demonstrating novelty and stimulation order influences on psychophsyiological outcome as a result of prolonged stimulus repetition .

Adaptation (i.e., habituation) always occurs to the repeated presentation of the same stimulus or relatively similar stimuli of the same modality (such as horns produced by different companies), except in cases of unusually intense stimulation (e.g., more than 105 dB) [5,6,13,21,26]. It was shown, nevertheless, that habituation is slower the greater the intensity of stimulation, the more unique the stimulus, and the more complex the stimulus is[8]. When stimuli lose their distinctive meaning and became highly predictable, habituation ensues. Habituation course variations may have orienting response (OR) re-installment [8,11] or other theoretical explanation, such as sensitization in dual-process habituation hypothesis [13,15] .

Orienting response is comprised of the following psychophysiological patterns: increased sensitivity of sensory systems, dilation of cerebral and constriction of peripheral vessels, deceleration-acceleration pattern of HR, increased skin conductance (SCL), increased beta in EEG and alpha blocking [5,8,21]. OR enables to attend to novel stimulus and facilitates an adaptive response to it but, once the stimuli poses no more real treat, the OR habituates [2,5,6,8]. After habituation, however, OR re-installment follows changes in stimulus intensity, modality, duration, frequency, sequence, complexity and significance [6,8,9,22]. Namely, dishabituation may also be elicited by changes in frequency components of acoustic probe within the same stimulus modality [18,20,26,27]. Role of stimulus significance and novelty was discussed elsewhere in details in psychophysiological literature, since for a certain period of time it was a hot topic of intensive debates [2,3,5,12,15,19,20,22].

The defense response is elicited by strong stimulus that may be dangerous and in contrast to OR defense response (DR) habituates slowly. DR is associated with both central and peripheral vasoconstriction, monophasic increase in HR[8,21]. One of the main distinguishing features of DR are behavior of vasomotor component and higher level of cardiovascular activation. Startle response is a pattern that arises from sudden stimulation. It consists in HR acceleration (peak latency - 4 s), digital vasoconstriction, habituation rate dependent on intensity [8,13,26]. These similarities of startle and DR enabled Turpin (1986) to claim that the startle reaction should be considered as an early component of a DR, elicited by stimuli with short rise time. Anyway, all above considerations suggest that psychophysiological effects of such intense acoustic stimuli as car horn should be considered with regard to the concepts of startle, orienting and defense reflexes, as well as taking into account principles of habituation, autonomic reactivity and stimulus-response specificity.

Autonomic variables are widely used in research of processes related to OR and habituation. Among physiological indicators of habituation, skin conductance response (SCR) is the most frequently used, and is featured by decreased amplitude over trials, but the same time digital vasomotor parameters (i.e., pulse volume) are also popular measures along with other cardiovascular variables [3,6,8,9,13,18,19,27]. A repeated presentation of stimuli eliciting a DR should not theoretically lead to habituation. Groves and Thompson (1970) pointed to a hypothetical sensitization process underlying the phenomenon of delayed or missing decrease of reaction strength with repeated stimulus presentation. In their two-process theory of habituation, authors regarded the course of reaction amplitudes over trials as resulting of interacting habituation and sensitization processes [15]. Some authors [26,27] preferred term dishabituation instead of sensitization. However, as it was outlined by Baltissen and Boucsein (1986) the fact that electrodermal DR component does not show habituation still remains debatable. Both [1,8] and [26,27,28] showed that after initial delay of habituation, there was still SCR amplitude habituation during 15 trial series. Particular technique intended to differentiate physiological responses elicited by horn stimulation may become insensitive with increased number of trials, since experimental subjects should reach stable low SCR (amplitude, rise time etc.) with large number of trial even if order of stimuli would be counterbalanced. The problem may be solved by different approaches: 1) including only the first part of trials in statistical analysis(i.e., when stimuli are still significant and novel and habituation rate is relatively low); 2) application of high of auditory stimulation to ensure DR rather than OR; 3) entering variability in stimulus characteristics (e.g., varying frequency components of horns); 4) removing the trend of most habituation prone variables if this is possible technically.

The goals of current study were comparative analysis of physiological responses evoked by auditory stimulation with automobile horns, identification of phasic and tonic autonomic reactivity to startling acoustic probe capable to elicit orienting and/or defensive reaction, investigation of habituation course of electrodermal and cardiovascular reactivity, as well as attempt to differentiate physiological responses to horn pairs subjectively evaluated as most and least preferred, appropriate and arousing.

Methods

Ten college students (19-23 years old) participated in this study . Physiological signals (ECG, finger photopletysmogram/PPG/, skin conductance and pneumogram) were recorded by BIOPAC, Grass Neurodata System and Acqknowledge III software. The following autonomic variables were measured for each condition: heart rate (HR), respiratory sinus arrhythmia index (RSA calculated as difference between minimum and maximum HR in each respiration cycle)[7,14], pulse transit time (PTT - time delay between R-wave of ECG and relevant maximum of pulse wave in PPG in the same cardiac cycle)[17], pulse volume amplitude (PV), respiration rate (RSR), skin conductance level (SCL), skin conductance response (SCR) amplitude and rise time[4]. RSR was not included in final analysis, due to unreliability of measure for short-term response to stimulation, but pneumogram was used during raw data processing for more accurate estimation of RSA variable. To evaluate phasic responses of variables there were calculated differences between values of each variable during stimulation and relevant resting baselines (e.g., phasic HR response to horn1 (mix) was calculated as [dHRhorn1mix]=[HRhorn1mix]-[HRbaseline1]). For better comparability of reactivity differences were also standardized, i.e., calculated as percentage changes from baseline (e.g., rHR - change of HR in percents from baseline). Tonic values were defined as absolute values of parameter during stimulation condition (SCL, HR etc.). Thus both phasic and tonic physiological reactivity to auditory stimulation were assessed.

Experimental procedure consisted in adaptation and 3 blocks of experimental sessions. Each session comprised from 20 s recording of resting baseline and 5 s long trial of stimulation by automobile horn. In the first session there were used 7 different horns ("mixed" mode, e.g., both high and low frequency bands). In the second sessions same 7 horns were used but in different order and only with high frequency components of horn ("high" mode), while in the third session once again the same horn were presented in new order but with only low frequency bands ("low" mode). After each stimulation trial subjects were requested to fill in paper questionaires regarding subjective rating of appropriatness, preference and arousalabilty of delivered horn stimulation.

Thus each horn was presented 3 times with different complexity of stimulation, however "high" and "low" mode did not correspond to higher or lower intensity, but rather reflected specific frequency band of horns, which usually are constructed from 2 components (left-right) with slightly different acoustic features. Manipulation of complexity of each horn was intended to introduce novelty of stimuli and avoid habituation effect. Technical characteristics of employed horns are presented in Table 1.

Results

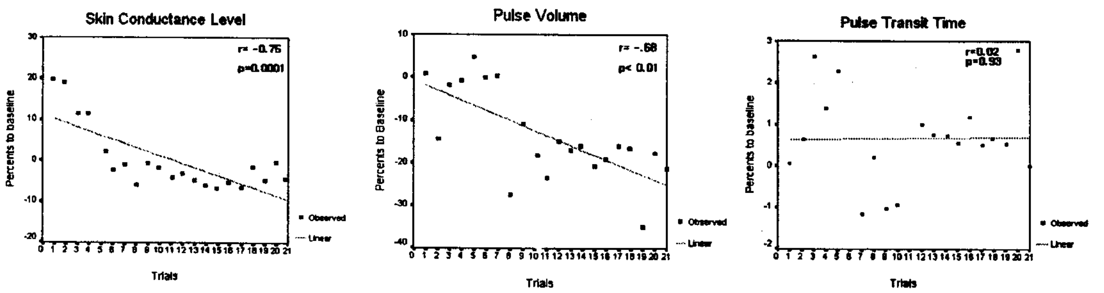
Electrodermal and cardiovascular baseline levels tonic drifts. Regression analysis showed linear trend of baseline levels to decrease by the end of experiment for some cardiac variables (HR, $r=-0.70$, $p<0.01$; RSA , $r=-0.59$, $p<0.05$), but not for vascular parameters (PV, PTT) and SCL.

ANS reactivity trends (habituation). ANS responsivity to stimulation with increasing number of trials was analyzed by regression method to demonstrate habituation and decrement of the reactivity with repeated stimulation. Electrodermal activity was found to be most habituation prone since all skin conductance variables exhibited profound linear decrement trends . SCL decreased with linear $r=-0.75$ ($p<0.01$), SCR amplitude with $r=-0.45$ ($p<0.05$), as well as most dramatically reduced SCR rise time ($r=-0.81$, $p<0.01$) and percentage of scorable SCRs to stimulation (−0.84, $p<0.01$). On opposite, cardiovascular variables did not manifest decrement of reactivity and remained reactive over whole trials. Namely, PTT and RSA did not showed any drift of reactivity, HR responses slightly tended to be enhanced with increased number of trials , while PV decrease responses were significantly facilitated with repeated stimulation ($r=-0.68$, $p<0.01$). Thus, no signs of cardiovascular habituation was detected, furthermore, vascular components of cardiovascular response (e.g., pulse volume) showed sensitization tendency. Figure 1. demonstrates trends of standardized SCL and PV over horn stimulation trials.

Table 1. Technical and psychoacoustic 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/flatl/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

Figure 1. Regression analysis of standardized SCL change, finger pulse volume (PV) amplitude 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.



Differentiation of subjectively different horns by physiological responses.

Analysis of autonomic response differences with relevance to subjective rating data showed that in preference category the most preferred horn (Hella/100phi/shell, Germany) evoked cardiac and electrodermal responses different from the least preferred horn (Knight horn/100phi/flat, Japan). However, electrodermal differentiation was significant (e.g., tonic SCL higher in preferred by 2.54 μS, $p< 0.05$) , or close to significance level (phasic dSCL, $p=0.059$, SCR amplitude higher in preferred at 1.39 μS, $p=0.06$) only in first session ("mixed" horns), while both phasic HR and tonic RSA differentiation was valid in "high" and "low " sessions (e.g., HR accelerated 3.86 bpm more to Hella than to Knight horn, $p<0.05$; while RSA was 1.42 bpm lower, $p<0.05$). Differentiation of physiological responses according to subjective "appropriatness" rating was significant only in "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 to the most preferred horn (0.64 μS, $p<0.05$), with trends to 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.

Differentiation by "arousalability" rating yielded only significantly lower tonic HR (Knight/100phi/flat, Japan, most arousing) in "low" session as compared to least arousing horn (Mixo/100phi/shell, France) and less HR acceleration as result of exposure to most arousing horn in "high" session (Knight/100phi/flat vs.

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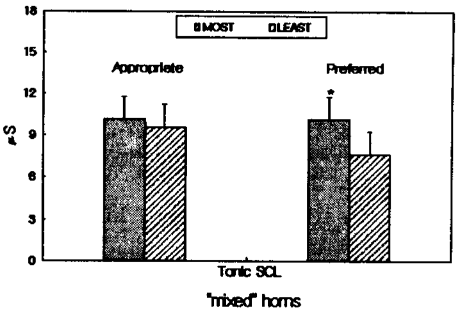

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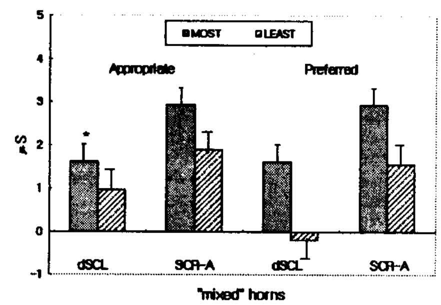

Figure 2. Differentiation of electrodermal responses (Means with SE) to the most and least appropriate and preferred horns in the first (mixed) stimulation session. Fig. 2.a. shows differences of basal (tonic) SCL, while Fig. 2.b. differences of phasic SCL changes (dSCL) and SCR amplitudes. Asterisks show significance of differences. * $p<.05$

Hella/100phi/shell). Thus, differentiation by "appropriatness" and preference rating was effective in "mix" only (both SCL and HR, RSA), while in "high" and "low" conditions only HR and RSA showed significance of differences in most vs. least preferred , appropriate, or arousing horns. Some of differentiation results are presented in Figures 2 and 3..

Habituation of subjective rating scores. Regression analysis demonstrated significantly unchanged "preference" rating with increased number of trials (linear trend $r=-0.02$, $p=0.99$), as well as

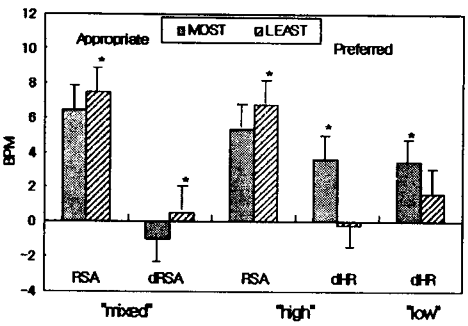

Figure 3. Differentiation of phasic (dHR, dRSA) and tonic (RSA) cardiac responses to the most and the least subjectively appropriate and preferred horns in the first (mixed), the second (high) and the third (low) sessions of auditory stimulation. Mean values are presented with SE (N=10). Significant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

practically unchanged "appropriatness" scores, whereas "arousing" rating scores demonstrated tendency to incline (logarithm trend r=0.41, p=0.06), featuring increment of arousing qualities of stimulation by end of experimental sessions.

Correlation analysis of physiological variables and subjective rating scores.

Positive correlation among subjective rating scores was significant only for "appropriateness"-"arousal" pair (r=0.67, p<0.01) , while "preference"-"arousal" scores tended to have negative correlation (r=-0.34, p>0.1). "Preference" did not correlated 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).

Correlation analysis performed for standardized cardiovascular and electrodermal responses (expressed in percentage of changes from baseline) revealed positive correlation of PV and SCL (r=0.59, p<0.01), PV and SCR rise time (r=0.67, p<0.01); SCR amplitude and SCR rise time (r=0.54, p<0.05), and SCR amplitude and SCL (r=0.74, p<0.01), as well as SCR rise time and SCL (r=0.81, p<0.01).

Discussion

Patterns of habituation of variables

There was observed skin conductance response decrement during experimental sessions, which occured almost in any type of studies with repeated acoustic stimulation. Habituation of phasic SCRs repeated trials was described in most of the studies of electrodermal reactivity to the sudden loud stimuli [5,6,8,13,16]. Electrodermal activity in our study habituated and matched these data, whereas cardiovascular activities failed to habituate. Tonic cardiac activity (HR, RSA) was facilitated, as well as phasic vascular responses (PV) suggesting manifestation of cardiovascular sensitization as proposed in dual-process theory of habituation [15], or in other words dishabituation [26]. Increment of cardiac reactivity might also be due to detected trends of baselines of HR and RSA, but it does not seem probable that increased phasic cardiac activity was determined merely by law of initial values.

There is extensive literature documenting HR acceleration following stimulation intense enough (85-110 dB) [13,28], and the observed pattern of HR increment has been reported elsewhere in respect to less intensive (80-100 dB) but longer (up to 5 s) burst of white noise [13]. The important finding is that ANS responses to startling auditory stimulation had 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 [15, 23,24]. In dual-process theory, two independent processes of habituation and sensitization occur in response to repetitive stimulation. Habituation influences the stimulus-response type and is decremental process, while sensitization influences the reactivity state of the subject and is incremental process [15]. In our study only electrodermal activity showed decrement of response and marked habituation, while vascular reactivity was facilitated, and overall cardiovascular activity (HR, RSA, PTT) that presumably reflect tonic state failed to show habituation. The distinctive facilitation of cardiac and vascular activity indexes sensitization process, which is related to induced tonic arousal suggesting that repetitive startling stimulation is stressful [1,16] and this notion is supported also by positive trend of "arousalability" scores found in our study. The major characteristic of the habituation, was a significant linear decline in response magnitude (amplitude, time, number of responses etc.) across trials. Phasic SCR is one of the most suitable correlate of stimulus intensity, as compared to HR or pulse volume [2,4,5,8,9] . Sensitization of vasomotor response confirms as well that auditory stimulation with horns evoked responses more relevant to DR, since only electrodermal indices are not sufficient to differentiate DR and OR [8,28]. In mutiprocess OR model proposed by Barry (1984) stimulus register is indicated in HR and cerebral pulse changes, intensity in SCR and peripheral pulse volume, while novelty in alpha EEG, SCR, respiration break and motor response system, the activation of which is accompanied by HR acceleration [3,5]. Most of our results in this study are in accord with this multiprocess model. Obtained data are either suggesting what might be possible autonomic mechanisms that mediate observed responses.

Autonomic nervous system mechanisms. Sympathetic innervation normally produces constriction of vessels and maintain vasomotor tone, but both constriction and dilation are sympathetically regulated. Blood vessel diameter is controlled to a large extent by the sympathetic (alpha-adrenergic) nervous system. BP changes (judged by PTT) may be produced by different patterns of cardiodynamic and hemodynamic events. Baroreceptors functioning results in inverse relationships between changes in BP and direction of chages in both cardiac and vasomotor tone. Pulse transmission time, when it is measured from R-wave of ECG is affected both by beta- and alpha -adrenergic influences (both cardiodynamic and hemodynamic factors) [17]. This might be partially an explanation of relatively low reactivity of PTT in our study. Complex interactions between sympathetic and parasympathetic innervations of heart have been well documented [7,25], and the most prominent resultant interaction to affect cardiac chronotropic function is parasympathetic inhibition of sympathetic effects on the heart, named accentuated antagonism. Magnitude of phasic HR changes due to apparent autonomic interactions in chronotropic control is less sensitive to basal tonic HR levels. Our results showed marked parasympathetic reactivity indexed by RSA responses, but beta-adrenergic sympathetic influences (PTT and HR acceleration indices) were masked by prevailing peripheral alpha-adrenergic mediated effects (vasoconstriction) , suggesting, however, sufficiently high overall sympathetic background typical for defensive reactions. Cardiac and vascular components of reactivity in this study are nevertheless quite difficult to differentiate only in terms of shifts in autonomic balance, since such intense and significant auditory stimulation as automobile horn elicits centrally integrated defensive reflex where autonomic responses represent only part of generalized reactions.

Conclusions

Auditory stimulation with automobile horns evoked autonomic responses in a form of HR acceleration, RSA decrease, finger pulse volume decrease, moderate PTT increase, and electrodermal activity expressed in increase of SCL and SCR of high amplitude.

Increased number of trials of repetitive stimulation with 7 different horns in 3 sessions with varying complexity of auditory stimuli led to habituation of electrodermal responses, but failed to demonstrate adaptation of cardiac reactivity, furthermore vascular responsiveness to stimulation was facilitated. Concurrent course of habituation of electrodermal and cardiovascular activity could be explained by sensitization of vascular responses typical for defensive 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 manifestations (SCL, SCR amplitude) and by parasympathetic activity indexed by respiratory sinus arrhythmia of heart rate, 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), due to strong habituation effects on electrodermal reactivity.

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