Appl Psychophysiol Biofeedback (2014) 39:9–18
DOI 10.1007/s10484-013-9235-4

Cardiovascular Effects of Acute Positive Emotional Arousal

Helmut K. Lackner · Elisabeth M. Weiss · Helmut Hinghofer-Szalkay · Ilona Papousek

Published online: 16 October 2013

Abstract Since there are several popular beliefs about putative health benefits of amusement which are empirically substantiated poorly about putative health benefits of amusement, the immediate cardiovascular effects of amusement were studied in detail. Cardiovascular activity was studied while participants were viewing humorous films, relative to a control condition involving no amusement. High-resolution measures of heart rate, heart rate variability, continuous blood pressure, and respiration were recorded, and the phase synchronization among the variables was analyzed, which provides information on the coordinated behavior of response systems. Viewing humorous films had cardiovascular effects indicating heightened sympathetic arousal, if they elicited intense amusement. No effects were observed for variables indicating parasympathetic input to the heart. The observed effects associated with amusement were not driven by changes in the respiration. The suppression of positive affect expressions did not produce any additional activation. The transient cardiovascular effects of amusement do not correspond to beneficial correlates of a habitual positive affect disposition reported in the literature, demonstrating that it would be erroneous to argue from the long-term effects of a positive affect disposition to the effects of a single amusing event.

Keywords Humor · Emotional arousal · Expressive suppression · Sympathetic nervous system · Heart rate · Heart rate variability

Introduction

It is often believed that the experience of positive emotional states may be beneficial against cardiovascular disease. Indeed, there is some evidence that a positive affect disposition may constitute a protective factor (Davidson et al. 2010; Steptoe et al. 2009). However, it would be a mistake to conclude that the benefits of an individual's habitual disposition toward positive moods do also apply for single transient states of positive affect. Neither do the cumulative short-term psychophysiological effects of transient mood states necessarily match the long-term effects of a habitual affect disposition (Dockray and Steptoe 2010; Papousek and Schulter 2010; Pressman and Cohen 2005). From these considerations, it follows that, in addition to highly valuable prospective studies of the long-term effects of affective traits, it is important to also study the physiology of short-lived intense feelings.

It is true, of course, that in most cases, transient physiological responses to emotion-eliciting events are of no clinical importance in themselves. Accumulation of these effects over longer intervals may eventually have pathophysiological significance (Chida and Hamer 2008). More importantly, the evaluation of autonomic changes during intense emotional arousal may be relevant, because the autonomic modulation of the cardiovascular system is

H. K. Lackner (✉) · E. M. Weiss · I. Papousek
Biological Psychology Unit, Department of Psychology, University of Graz, Universitaetsplatz 2/DG, 8010 Graz, Austria
e-mail: h.lackner@uni-graz.at

E. M. Weiss
e-mail: e.weiss@uni-graz.at

I. Papousek
e-mail: ilona.papousek@uni-graz.at

H. K. Lackner · H. Hinghofer-Szalkay
Institute of Physiology, Medical University of Graz, Graz, Austria
e-mail: helmut.hinghofer@medunigraz.at

likely to be important in the pathogenesis of acute coronary syndromes such as myocardial infarction and sudden cardiac death (Bhattacharyya and Steptoe 2011; Lahiri et al. 2008; Miyazaki and Zipes 1990). In patients with coronary artery disease, even short periods of intense emotional arousal may trigger the onset of acute coronary syndromes (Mittleman et al. 1995; Pressman and Cohen 2005; Samuels 2007; Strike and Steptoe 2005). In general, most research in the field has focused on negative affect such as anger and depression, whereas positive affect is relatively underexplored.

Moreover, the current clinical zeitgeist is also to argue that the habit to suppress one's feelings can be maladaptive and should be discouraged (Dunn et al. 2009). Early psychosomatic ideas were based on the assumption that the suppression of unwanted feelings would be associated with higher physiological responses, which in turn was considered to be unhealthy (Alexander 1939). More recently, it has been suggested that overriding emotion response tendencies require an active inhibitory process, that is, effort, which may be accompanied by additional cardiovascular activation (Gross and Levenson 1993). Suppression, too, has primarily been investigated in the context of negative affect so far.

The purpose of the present investigation was to study in detail the immediate cardiovascular effects of acute positive emotional arousal as well as of the active suppression of its outward expression, in order to evaluate several several popular beliefs about putative health benefits of amusement and laughter which are empirically substantiated poorly (Martin 2001; Papousek and Schulter 2010).

Previous research has shown that positive affect, if intense enough, causes a transient increase in heart rate and blood pressure (Herring et al. 2011; Neumann and Waldstein 2001; Pressman and Cohen 2005). Additionally, studies on the immediate cardiovascular effects of expressive suppression (mostly after the induction of disgust) reported findings that were inconclusive in so far as the suppression of emotional expressions was accompanied by lower heart rates as compared to a natural viewing condition; but at the same time by greater changes in a composite measure of finger pulse amplitude, pulse transmission time, and finger temperature, which were interpreted as activation of the sympathetic nervous system (Gross and Levenson 1993; Roberts et al. 2008). Other studies did not replicate the latter effects (Kunzmann et al. 2005). Cardiovascular effects of the control of positive affect expression have rarely been investigated (Gross and Levenson 1997).

To date, the cardiovascular consequences of amusement and of the suppression of its expression have not yet been analyzed in a very detailed way as far as the physiology is concerned. For instance, little is known about the autonomic changes that may underlie increases in heart rate or blood pressure, and it has not yet been explored how much of the cardiovascular changes is explained by changes in the respiratory patterns (produced, e.g., by incipient or stifled laughter).

In the present study, high-resolution measures of heart rate, continuous blood pressure, and respiration were recorded and their interactions were analyzed. To provide a more in-depth analysis of the interaction between response systems, the phase synchronization of heart rate, blood pressure, and respiration was analyzed. Phase synchronization provides a quantitative indicator of the coordinated behavior of response systems (Lackner et al. 2011; Rosenblum et al. 2004; Schaefer et al. 1999).

The cardiovascular activity was studied while participants were viewing humorous film clips, relative to a baseline condition involving no amusement (emotionally neutral films). In addition, potential additional effects of the suppression of the outward expression of amusement were studied. As individuals differ greatly in which kind of humor they appreciate and how funny they find it (Ruch 1998), the cardiovascular changes were studied in groups of participants who were susceptible to the humor in the films and participants who were not susceptible or were susceptible only to a limited extent (according to the experience of amusement reported on rating scales after each film). That way, the cardiovascular changes during viewing the films could more unequivocally be attributed to the actual experience of amusement.

Methods

Participants

Forty-eight female undergraduates (mean age 21.0 ± 2.7 years) were participated in the study (45.8 % Caucasian, 14.6 % Hispanic, 12.5 % African American, and 27.1 % Asian American). Because gender and age may affect cardiovascular variability, participation was limited to women aged between 18 and 35, who were not taking medication for known cardiovascular problems or psychiatric disorders. The study was performed in accordance with the Declaration of Helsinki and was approved by the local ethics committee. The participants provided written informed consent and received course credit or $20 for their participation.

Stimuli

Three film clips (each approx. 60 s) were assigned to each of the three conditions (neutral, humorous natural viewing, humorous expressive suppression) and were presented consecutively without interruption, that is, one film block lasted for 3 min, during which the physiological data were recorded. The clips were selected from a pool of scenes according to amusement ratings in a pilot study. The pilot data confirmed that, on average, high levels of amusement were evoked by each of the humorous 1-min clips: the average amusement rating was $M = 4.03$ ($SD = 0.35$, $n = 15$) on a scale from 1 to 5. The humorous film stimuli were composed of several slapstick scenes and jokes from various movies and TV programs, ensuring that humor and its physiological concomitants were present right from the beginning of the recording periods onwards. Recently, it was demonstrated that the recognition of the funny punch lines of single jokes was immediately followed by cardiac responses (Lackner et al. 2013). The assignment of the humorous film clips to the natural viewing versus expressive suppression condition,[1] the order of the blocks, and the positions of the film clips within each block were counterbalanced across participants.

Physiological Measurement

Continuous hemodynamic monitoring of blood pressure (BP), heart rate (HR), and thoracic impedance was carried out with the Task Force® Monitor (TFM®; CNSystems, Graz, Austria). HR was recorded by 3-lead electrocardiography (ECG; sampling rate = 1 kHz, $f_{cut\text{-}off}$ = 0.08–150 Hz) using CNSystems ECG electrodes placed at the thoracic region. Continuous BP (sampling rate = 100 Hz, BP_{range} = 50–250 mmHg, ±5 mmHg) was derived from the finger using a refined version of the vascular unloading technique and corrected to absolute values with oscillometric BP measurement on the contralateral upper arm. The method is based on concentrically interlocking control loops for correct long-term tracing of finger BP and delivers, in contrast to intermittent set point re-adjustments of the conventional vascular unloading technique, BP without interruptions (Fortin et al. 2006a). For thoracic impedance measurement, three CNSystems short-band electrodes (two electrode bands set at a predefined distance onto a common adhesive medium; sampling rate = 500 Hz, $I_{eff} < 400\mu A$, $f = 45$ kHz, $Z_{0,range}$ = 10–75 Ω, $dZ/dt = \pm 10$ Ω/s) were placed onto the participant: one placed at the nape of the neck close to the glottis, two others placed on the thorax close to the xiphoid (see Fortin et al. 2006b).

The heart rate provides an index of the net effects of sympathetic and parasympathetic inputs to the sinus node (Miyazaki and Zipes 1990). Measures of heart rate variability assess modulation of autonomic control of heart rate and provide information regarding sympathetic or parasympathetic input individually. Nonlinear indices of heart rate variability can provide additional information to traditional measures, which have been shown to be independently relevant to cardiovascular morbidity (Lahiri et al. 2008; Stein et al. 2005). Increased blood pressure variability in response to challenge has been linked to an unfavorable reduction in cardiac autonomic control (Sloan et al. 1999; Taylor and Eckberg 1996).

Procedure

After the finger cuff, the arm cuff, and the electrodes were attached, the participants completed some questionnaires that are not relevant to the present research question. An example of the films was presented and the procedure was explained, before the first film block was started. A break of 3 min was observed before the presentation of the next film block. After each film block, the participants were asked to retrospectively rate their amusement produced by each clip on a scale from 1 ("not at all") to 7 ("very strong"; "How amused did you feel during this video?"). As a reminder of which film clip the participants were asked to rate, a representative still image of the clip was presented on the screen. Before the neutral film block and before the humorous film block in the natural viewing condition, the participants were instructed to attend naturally to the upcoming three film clips and to express their feelings as they usually do when viewing movies. Before the expressive suppression condition, the participants were instructed to hide their feelings during the upcoming three film clips, so that a naive observer would not realize they were viewing films. During the whole procedure (total duration 25 min), the participants remained seated, were asked not to talk or make abrupt movements, and were monitored online by the experimenter to ensure high signal quality.

Data Reduction and Analysis

To obtain R–R intervals and blood pressure time series with equidistant time steps, the beat-to-beat values were resampled with 4 Hz using piecewise cubic spline interpolation after artifact correction. The full respiratory signal was derived from the raw data of thoracic impedance (Ernst et al. 1999; Houtveen et al. 2006).

Time domain measures of heart rate variability were computed as the standard deviation of normal-to-normal beat (SDNN) and root mean squared successive differences (rMSSD) of R–R intervals. SDNN is related to the total variance, whereas rMSSD detect high-frequency (short-term) oscillations. Changes in short-term heart rate variability are mainly caused by changes in vagal tone. The nonlinear (geometrical) index SD2/SD1 of heart rate variability quantifies the shape of the Poincaré plot, which is a

[1] Data of one further humorous film block are not relevant to the present research question and will not be presented here.

graphical representation of the underlying patterns in the R–R time series. SD2/SD1 reflects the balance between long- and short-term variability, by analogy with LF/HF from spectral analysis, with higher values indicating increased sympathetic activity (Brennan et al. 2001; Task Force 1996).

For frequency domain measures of R–R intervals, the autoregressive Burg algorithm was used (model order 24), after resampling and removing the trend of second order. The advantage of the Burg algorithm over fast Fourier transform (FFT) is that parametric methods can yield higher resolutions than nonparametric methods in cases when the signal length is short. In estimating short data records, the autoregressive power spectral density estimates are very close to the true values. In addition, the Burg method ensures a stable autoregressive model and is computationally efficient. In most instances, both methods provide comparable results; however, for 3-min recordings, parametric methods are recommended (Task Force 1996). The low-frequency range (LF) was defined as 0.04–0.15 Hz, whereas the high-frequency range (HF) was defined as 0.15–0.40 Hz (Task Force 1996). Total power was also calculated (TOT_{RR}; frequency range $\leq$0.40 Hz). A natural logarithm (ln) procedure was employed to correct for skewed raw score distributions in the spectral data. HF_{RR} is generally thought to be mainly of parasympathetic origin, whereas LF_{RR} is considered as reflecting sympathetic influences on the heart but to be also contaminated by parasympathetic influence (Task Force 1996). The LF/HF_{RR} ratio represents the relative contribution of the two components, minimizing the influence of total power, with higher values of LF/HF_{RR} indicating relative increases in sympathetic activity.

Time domain measures of blood pressure variability were computed as the standard deviation (SD_{SBP}, SD_{DBP}). Blood pressure variability in the low-frequency range (LF_{SBP}, LF_{DBP}) was computed by analogy with the frequency domain measures of heart rate variability. Higher levels of beat-to-beat blood pressure variability characterize a more activated state. Low-frequency blood pressure variability is mediated by vascular sympathetic activity (Sloan et al. 1999).

In addition to the breathing rate (cycles per min), the proportion of regular breathing cycles ($Cycles_{Valid}$) and the variability of the breathing rate (standard deviation, $SD_{Breathing\ rate}$) were computed, which also reflects more irregularity in the breathing pattern.

Phase synchronization variables were calculated as described previously (Lackner et al. 2011; Moertl et al. 2013). In brief, the analysis of synchronization, e.g., of R–R interval and respiration is based upon the weak coupling of two chaotic systems. Each oscillator can be described by its amplitude and phase as a function of time. For the purpose of our study, only a phase (but not amplitude) needed to be defined for a time series that contains oscillations in a narrow frequency band. The time series phase definition for the R–R interval, blood pressure, and respiration was given using the concept of analytic signals (Cysarz et al. 2004). In the next step, the difference between two given phase vectors for the interpolated bivariate time series, e.g., in this case between R–R interval and respiration, was calculated. The time series are defined as synchronized if this phase difference is constant over time. In case of synchronization, the distribution of the phase difference shows a definite maximum where the it is quantified by the synchronization index γ. Theoretically, if the synchronization index $\gamma = 1$, both time series are completely synchronized in a statistical sense, while in the case of $\gamma = 0$, both time series are completely desynchronized (Lackner et al. 2011; Moertl et al. 2013).

Statistical Analysis

To unequivocally interpret the cardiovascular changes as the effects of experiential emotional arousal, the participants were divided into groups those who were susceptible to the humor in the films versus those who were not susceptible or were susceptible only to a limited extent, using the retrospective amusement ratings of the humorous films in the natural viewing condition (median split). The difference in the amusement scores between the two groups was statistically significant ($t(46) = 7.6$, $p < .001$; $M = 4.0$, $SD = .9$; $M = 5.5$, $SD = .4$).

The cardiovascular effects were analyzed using 3 × 2 analyses of variance (ANOVAs) with *Film Block* (neutral, humorous—natural viewing, humorous—expressive suppression) as a within-subject factor, *Humor Susceptibility* (low- vs. high-experienced amusement) as a between-subject factor, and the hemodynamic measures as the dependent variables. A two-tailed significance level of $\alpha = .05$ was used for the analyses. Bonferroni correction for multiple comparisons yielded critical p values of $p < .013$, $p < .013$, $p < .008$, $p < .017$, and $p < .007$ to indicate statistical significance in the analysis of time domain, frequency domain, blood pressure, respiratory, and phase synchronization variables, respectively. An analogous ANOVA was performed with the subjective ratings of amusement as the dependent variable. In case of significant ANOVA effects, Bonferroni-corrected post hoc tests were performed.

Results

Amusement Ratings

The participants in the group who was more susceptible to the humor in the films reported a significant increase in amusement during viewing the humorous film blocks as compared to the neutral film block. In addition, they reported a relatively lower level of amusement during the expressive suppression condition as compared to the natural viewing condition (neutral block: $M = 2.0$, SD = 1.0, humorous natural: $M = 5.5$, SD = .4, humorous suppression: $M = 4.9$, SD = 1.0). The less-susceptible group also reported some amusement during viewing the humorous film blocks. However, the level of amusement was lower that that of the more-susceptible group, and there was no significant difference between the natural viewing and the expressive suppression conditions (neutral block: $M = 2.0$, SD = 1.0; humorous natural: $M = 4.0$, SD = .9; humorous suppression: $M = 4.5$, SD = 1.3; interaction film block × humor susceptibility $F(2,92) = 10.1$, $p < .001$, $\eta_p^2 = .18$; main effect Film Block $F(2,92) = 177.1$, $p < .001$, $\eta_p^2 = .79$; Bonferroni-corrected post hoc tests).

Heart Rate and Heart Rate Variability

Time Domain Variables

The interaction film block × humor susceptibility was significant for heart rate ($F(2,92) = 7.6$, $p < .01$, $\eta_p^2 = .14$), SDNN ($F(2,92) = 7.7$, $p < .01$, $\eta_p^2 = .14$), and SD2/SD1 ($F(2,92) = 6.0$, $p < .01$, $\eta_p^2 = .12$), but not for the parasympathetically dominated rMSSD ($F(2,92) = 1.7$, ns.). The main effects of Film Block were not significant. Means and standard deviations are shown in Table 1.

Table 1 Time domain variables of heart rate variability as a function of film block and humor susceptibility

	(1) Neutral film block	(2) Humorous film block natural viewing	(3) Humorous film block expressive suppression
Heart rate (bpm)			
Amusement low	70.4 ± 12.7	69.4 ± 12.6	69.8 ± 12.5
Amusement high	71.7 ± 8.2[2]	73.8 ± 6.7[1,3]	70.6 ± 7.2[2]
SDNN (ms)			
Amusement low	66.3 ± 31.0	59.8 ± 23.4	63.1 ± 33.8
Amusement high	63.5 ± 24.4[2]	81.9 ± 40.3[1,3]	69.7 ± 26.9[2]
rMSSD (ms)			
Amusement low	53.3 ± 33.5	52.2 ± 31.7	52.5 ± 31.3
Amusement high	53.7 ± 26.4	55.1 ± 28.1	59.0 ± 26.1
SD2/SD1			
Amusement low	2.55 ± 0.86	2.44 ± 1.04	2.40 ± 1.03
Amusement high	2.28 ± 0.74[2]	2.93 ± 1.06[1,3]	2.24 ± 0.57[2]

Mean ± standard deviation. Superscript digits 1, 2, and 3 indicate significant post hoc comparisons made within each group (humor susceptibility: low- vs. high-experienced amusement). The digits refer to the film blocks from which the respective film block differs significantly. Significant interaction effects (film block × humor susceptibility) were observed for heart rate, SDNN, and SD2/SD1

Frequency Domain Variables

The ANOVAs yielded significant interactions film block × humor susceptibility for $\ln(TOT_{RR})$ ($F(2,92) = 8.9$, $p < .001$, $\eta_p^2 = .16$), $\ln(LF_{RR})$ ($F(2,92) = 9.6$, $p < .001$, $\eta_p^2 = .17$), and $\ln(LF/HF_{RR})$ ($F(2,92) = 6.8$, $p < .01$, $\eta_p^2 = .13$), whereas the effect was not significant for $\ln(HF_{RR})$, which is related to the parasympathetic branch of the autonomic nervous system ($F(2,92) = .7$, ns.). The statistical results for the main effects of Film Block were $F(2,92) = 3.4$, $p < .05$, $\eta_p^2 = .07$, $F(2,92) = 5.4$, $p < .01$, $\eta_p^2 = .11$, $F(2,92) = 9.4$, $p < .001$, $\eta_p^2 = .17$, and $F(2,92) = .7$, ns., respectively (Table 2).

Post hoc tests indicated that in less-susceptible participants, heart rate and heart rate variability remained stable across all conditions. In participants who were more susceptible to the humor in the films according to self-report, several variables indicating a higher sympathetic tone were increased during viewing the humorous film block naturally as compared to viewing the neutral film block. This was observed for heart rate and SDNN, which also resulted in a higher sympathovagal balance (SD2/SD1). These effects were even more pronounced for the variables in the frequency domain ($\ln(LF_{RR})$, $\ln(LF/HF_{RR})$). By contrast, no differences in cardiac activity were observed between viewing the neutral film block and viewing the humorous films in the expressive suppression condition. That is, the activating effect observed in more-susceptible participants during naturally viewing the humorous films was absent when they were suppressing emotional expressions.

Blood Pressure and Blood Pressure Variability

No interaction effect was found for the variables related to systolic blood pressure (SBP $F(2,92) = .1$, ns.; SD_{SBP} $F(2,92) = 3.3$, ns.), except $\ln(LF_{SBP})$ ($F(2,92) = 5.2$, $p < .008$, $\eta_p^2 = .10$). Similarly, the interaction effects were nonsignificant for diastolic blood pressure variables (DBP $F(2,92) = .2$, ns.; SD_{DBP} $F(2,92) = 4.4$, ns.) with a trend for $\ln(LF_{DBP})$ ($F(2,92) = 4.9$, $p = .01$, $\eta_p^2 = .10$). Significant main effects of Film Block were found for the blood pressure variability variables $\ln(LF_{SBP})$ ($F(2,92) = 9.5$, $p < .001$, $\eta_p^2 = .17$) and $\ln(LF_{DBP})$ ($F(2,92) = 5.1$, $p < .008$, $\eta_p^2 = .10$) but not for SD_{SBP} ($F(2,92) = 3.8$, ns.) or SD_{DBP} ($F(2,92) = 3.5$, ns.) Furthermore, the main

Table 2 Frequency domain variables of heart rate variability as a function of film block and humor susceptibility

	(1) Neutral film block	(2) Humorous film block natural viewing	(3) Humorous film block expressive suppression
$\ln(TOT_{RR})$ (ms^2)			
Amusement low	7.92 ± 0.72	7.75 ± 0.73	7.76 ± 0.84
Amusement high	7.48 ± 0.87[2]	8.27 ± 0.86[1,3]	7.89 ± 0.76[2]
$\ln(LF_{RR})$ (ms^2)			
Amusement low	6.99 ± 0.71	6.84 ± 0.68	6.70 ± 0.82
Amusement high	6.72 ± 0.93[2]	7.40 ± 0.89[1,3]	6.96 ± 0.71[2]
$\ln(HF_{RR})$ (ms^2)			
Amusement low	6.51 ± 1.01	6.38 ± 1.08	6.49 ± 0.93
Amusement high	6.57 ± 1.09	6.61 ± 0.94	6.67 ± 0.95
$\ln(LF/HF_{RR})$			
Amusement low	0.48 ± 0.85	0.45 ± 0.84	0.21 ± 0.83
Amusement high	0.14 ± 0.80[2]	0.79 ± 0.67[1,3]	0.29 ± 0.58[2]

Mean ± standard deviation. Superscript digits 1, 2, and 3 indicate significant post hoc comparisons made within each group (humor susceptibility: low- vs. high-experienced amusement). The digits refer to the film blocks from which the respective film block differs significantly. Significant interaction effects (film block × humor susceptibility) were observed for $\ln(TOT_{RR})$, $\ln(LF_{RR})$, and $\ln(LF/HF_{RR})$

effects of Film Block were not significant for systolic ($F(2,92) = .8$, ns.) or diastolic ($F(2,92) = 1.7$, ns.) blood pressure level. The effects were mainly due to a relatively reduced blood pressure variability in the expressive suppression condition, in which the blood pressure levels did not differ from the other conditions, however.

Respiration

A significant interaction was observed for $SD_{Breathing\ rate}$ ($F(2,92) = 4.2$, $p = .017$, $\eta_p^2 = .08$) and the proportion of regular breathing cycles ($F(2,92) = 11.7$, $p < .001$, $\eta_p^2 = .20$). Post hoc tests indicated that in participants who were more susceptible to the humor in the films, the breathing pattern became more irregular during viewing the humorous film block naturally as compared to viewing the neutral film block and compared to viewing the humorous film block in the expressive suppression condition. No differences between the film blocks were observed in the less-susceptible group. The interaction effect was not significant for the breathing rate as such ($F(2,92) = .4$, ns.). The main effect of Film Block was significant for all

Table 3 Breathing rate variables as a function of film block and humor susceptibility

	(1) Neutral film block	(2) Humorous film block natural viewing	(3) Humorous film block expressive suppression
Breathing rate (min^{-1})			
Amusement low	17.3 ± 1.8	18.6 ± 2.1	17.9 ± 1.7
Amusement high	19.2 ± 2.4	20.2 ± 1.8	19.7 ± 2.0
$SD_{Breathing\ rate}$ (min^{-1})			
Amusement low	2.4 ± 1.0	2.9 ± 1.3	2.6 ± 1.0
Amusement high	2.8 ± 1.2[2]	4.1 ± 1.3[1,3]	3.1 ± 1.0[2]
$Cycles_{Valid}$ (%)			
Amusement low	88.9 ± 9.8[3]	91.1 ± 7.8	93.7 ± 5.5[1]
Amusement high	94.5 ± 5.4[2]	84.3 ± 10.7[1,3]	94.5 ± 4.7[2]

Mean ± standard deviation. Superscript digits 1, 2, and 3 indicate significant post hoc comparisons made within each group (humor susceptibility: low- vs. high-experienced amusement). The digits refer to the film blocks from which the respective film block differs significantly. Significant interaction effects (film block × humor susceptibility) were observed for $SD_{Breathing\ rate}$ and $Cycles_{Valid}$ (%)

respiratory variables (breathing rate: $F(2,92) = 15.7$, $p < .001$, $\eta_p^2 = .26$; $SD_{Breating\ rate}$: $F(2,92) = 16.5$, $p < .001$, $\eta_p^2 = .26$; $Cycles_{valid}$: $F(2,92) = 15.5$, $p < .001$, $\eta_p^2 = .25$), with the relatively lowest breathing rate and the most regular breathing pattern during the neutral film block. (Table 3).

Phase Synchronization

LF Components

Respiration was neither coordinated with the R–R interval ($\gamma_{Resp \times RR;LF}$ <=.06) nor blood pressure ($\gamma_{Resp \times SBP;LF} < .05$, $\gamma_{Resp \times DBP;LF} < .05$). That is, the causal relationships of these variables were not significantly higher than those that occur by pure chance (Lackner et al. 2011). This was expected, because the breathing rate was in the physiological range of 12–24 cycles/min, which corresponds to a frequency of 0.2–0.4 Hz. Therefore, $\gamma_{Resp \times RR;LF}$, $\gamma_{Resp \times SBP;LF}$, and $\gamma_{Resp \times DBP;LF}$ were not considered in the analyses of variance. The remaining phase synchronization variables implicating the LF components did not show significant film block × humor susceptibility interaction effects ($\gamma_{DBP \times SBP;LF}$: $F(2,92) = .5$, ns.; $\gamma_{SBP \times RR;LF}$: $F(2,92) = 2.0$, ns.; $\gamma_{SBP \times RR;LF}$: $F(2,92) = .7$, ns.) or main effects of Film Block ($\gamma_{DBP \times SBP;LF}$:

Table 4 Phase synchronization variables as a function of film block and humor susceptibility

	(1) Neutral film block	(2) Humorous film block natural viewing	(3) Humorous film block expressive suppression
$\gamma_{DBP\times SBP;LF}$			
Amusement low	.72 ± .15	.70 ± .15	.68 ± .12
Amusement high	.66 ± .11	.64 ± .16	.65 ± .11
$\gamma_{SBP\times RR;LF}$			
Amusement low	.44 ± .15	.39 ± .20	.36 ± .16
Amusement high	.34 ± .13	.31 ± .15	.35 ± .15
$\gamma_{SBP\times RR;LF}$			
Amusement low	.44 ± .14	.39 ± .18	.37 ± .17
Amusement high	.38 ± .12	.35 ± .18	.36 ± .15
$\gamma_{Resp\times RR;HF}$			
Amusement low	.57 ± .21	.54 ± .24	.64 ± .17
Amusement high	.60 ± .18[2]	.33 ± .22[1,3]	.57 ± .17[2]
$\gamma_{Resp\times SBP;HF}$			
Amusement low	.52 ± .20	.47 ± 27	.61 ± .18
Amusement high	.56 ± .25[2]	.31 ± .22[1,3]	.51 ± .22[2]
$\gamma_{DBP\times SBP;HF}$			
Amusement low	.18 ± .16	.19 ± .17	.24 ± .21
Amusement high	.20 ± .17	.12 ± .12	.14 ± .11
$\gamma_{SBP\times RR;HF}$			
Amusement low	.53 ± .20	.49 ± .22[3]	.59 ± .18[2]
Amusement high	.57 ± .22[2]	.33 ± .22[1,3]	.51 ± .19[2]

Mean ± standard deviation. Superscript digits 1, 2, and 3 indicate significant post hoc comparisons made within each group (humor susceptibility: low- vs. high-experienced amusement). The digits refer to the film blocks from which the respective film block differs significantly. Significant interaction effects (film block × humor susceptibility) were observed for $\gamma_{Resp\times RR;HF}$, $\gamma_{Resp\times SBP;HF}$, and $\gamma_{SBP\times RR;HF}$

$F(2,92) = .7$, ns.; $\gamma_{SBP\times RR;LF}$: $F(2,92) = 1.5$, ns.; $\gamma_{SBP\times RR;LF}$: $F(2,92) = 1.7$, ns.).

HF Components

The influence of the respiration on the diastolic blood pressure is generally low (Lackner et al. 2011) as was confirmed by low values of phase synchronization in $\gamma_{Resp\times DBP;HF}$ and $\gamma_{DBP\times RR;HF}$. Therefore, $\gamma_{Resp\times DBP;HF}$ and $\gamma_{DBP\times RR;HF}$ were not further analyzed. Significant interaction effects were observed for $\gamma_{Resp\times RR;HF}$ ($F(2,92) = 7.4$, $p = .001$, $\eta_p^2 = .14$), $\gamma_{Resp\times SBP;HF}$ ($F(2,92) = 5.2$, $p = .007$, $\eta_p^2 = .10$), and $\gamma_{SBP\times RR;HF}$ ($F(2,92) = 7.4$, $p < .005$, $\eta_p^2 = .12$), but not for $\gamma_{DBP\times SBP;HF}$ ($F(2,92) = 3.2$, ns.). Only in the group who rated themselves having been more amused by the humorous films, the phase synchronization measures implicating respiration were reduced during viewing the humorous film block naturally as compared to both the neutral film block and the expressive suppression condition (Table 4). The main effects of Film Block were also significant for these variables ($\gamma_{Resp\times RR;HF}$: $F(2,92) = 18.4$, $p < .001$, $\eta_p^2 = .29$; $\gamma_{Resp\times SBP;HF}$: $F(2,92) = 18.1$, $p < .001$, $\eta_p^2 = .28$; $\gamma_{SBP\times RR;HF}$: $F(2,92) = 15.8$, $p < .001$, $\eta_p^2 = .26$; $\gamma_{DBP\times SBP;HF}$: $F(2,92) = 1.5$, ns.).

Discussion

As compared to viewing emotionally neutral films, viewing humorous films (naturally) had effects on several cardiovascular measures indicating heightened sympathetic arousal, but only if the participants felt indeed amused by the films. In participants who were susceptible to the humor in the films, heart rate, total heart rate variability, and sympathovagal balance increased during viewing humorous films. Invariance of the variables related to the parasympathetic branch of the autonomic nervous system across the film blocks supported the notion that the increases in cardiac activity were sympathetic nervous system driven.

These results are in line with a previous study showing that subjective ratings of amusement were positively correlated with heart rate reactivity, but not with respiratory sinus arrhythmia and respiratory amplitude (Herring et al. 2011). As the increased cardiac activity during the humorous film block was observed in comparison with viewing emotionally neutral films, it is ensured that they were elicited by the specific effects of the humorous films, but not by the effects of viewing a film (any film). Moreover, the heightened sympathetic arousal during viewing the humorous films did only appear in connection with the experience of intense amusement. Therefore, the observed heightened sympathetic arousal can be interpreted as the transient psychophysiological effects of acute emotional arousal due to amusement (and not, for example, to some other possible differences between the neutral and the humorous films).

Reports that cardiovascular recovery from stressful experience was faster when positive than when negative mood was induced after it might have suggested that state positive affect may "undo" the effects of negative emotions by decreasing cardiovascular arousal (Fredrickson et al. 2000). But in view of the present and other results (Herring et al. 2011; Neumann and Waldstein 2001; Pressman and Cohen 2005; Sakuragi et al. 2002), it seems unlikely that a direct cardiovascular effect of positive emotion was observed. More likely, the induced positive affect may have produced an indirect effect by replacing the negative affective state after the stressful experience by a more positive one, potentially distracting the participants more from the negative experience (see also Brosschot and Thayer 2003; Papousek et al. 2011). Potentially beneficial vascular effects that were observed some time after viewing funny films during which sympathetic cardiovascular arousal was increased have to be expected to occur in a similar manner after every emotionally arousing event. That is, they may also occur after sadness- or anxiety-inducing ones and may reflect counterregulation after increased blood flow (Sugawara et al. 2010).

One might have suspected that the effects of amusement on the cardiac variables could be mainly driven by changes in respiration (e.g., because of effects induced by laughter or incipient laughter). In fact, the variance of the breathing rate was higher, and the percentage of regular cycles was lower during viewing humorous films naturally as compared to viewing the emotionally neutral film block. Suppressing the emotional expressions during viewing humorous films abolished this effect. However, the more in-depth analysis using the synchronization index, γ, suggested a genuine cardiovascular effect of amusement. The participants were allowed to breathe freely, and therefore, the breathing frequency was in the physiological range of 12–24 cycles/min, which corresponds to a frequency of 0.2–0.4 Hz. Decreased phase synchronization was observed in the variables related to the high-frequency components, but the respiration was not coordinated with the R–R interval or with the blood pressure in the low-frequency components. If the cardiac effects would mainly have been driven by changes in respiration, a decrease in the heart rate variability in the high-frequency range should have been observed during amusement, but instead increased heart rate variability in the low-frequency range was observed. That is, the respiration showed fluctuations in the high-frequency range, whereas increased variability in the low-frequency range was observed in the heart rate. This resulted in decreased phase synchronization between the two systems, suggesting that two separate processes were observed in parallel: one related to respiration and another one to cardiac arousal.

When the participants were instructed to suppress the outward expression of their feelings, viewing the humorous films had no cardiovascular effects whatsoever. That is, the cardiovascular activity and the synchronization between systems in the expressive suppression condition matched that during viewing the neutral film block. Thus, by suppressing the outward expression of amusement, the participants also seemed to downregulate (or eliminate) the amusement-related emotional arousal. In addition, no noteworthy effort seemed to be required for it. This finding is at odds with reports of heightened sympathetic activity during the suppression of disgust or sadness, which was interpreted to indicate the demanding nature of intentional emotion suppression (Gross and Levenson 1993; Roberts et al. 2008). One reason for this could be that positive affect may be easier to control than negative affect. In studies in which the participants were directly asked, controlling positive emotion was subjectively rated as being easier than controlling negative emotion (Kim and Hamann 2007; Mak et al. 2009). On the other hand, various studies demonstrated that posed facial expressions modified the experience of emotions. Posed expressions of emotions were shown to be accompanied by a stronger experience of the corresponding emotion as well as higher physiological changes associated with emotional arousal (Duclos et al. 1989; Levenson et al. 1990). It seems plausible, therefore, that the reverse should also be true, that is, voluntarily inhibiting the expression of an emotion may also reduce its experience (Strack et al. 1988). It may also be that the participants in the present study used other strategies than just expressive suppression, which were effective earlier in the process (Gross 1998). That is, participants might have redirected their attention away from the film or might have viewed it in a more detached way. By not letting themselves become amused from the outset, no forceful suppression of expressions of amusement may have been necessary. In a study in which it was examined whether participants actually used the regulation strategy as instructed, it was found that more than 50 % of the participants told to suppress their emotional expression while viewing an emotional film used at least some antecedent strategies such as distraction (Demaree et al. 2006). However, there was no difference between positive (amusement) and negative (disgust) films concerning this matter.

A limitation of the study is that due to the design of the experiment focusing on immediate (short-lived) effects of humor, it cannot be excluded that expressive suppression might have effects in the longer term. More far-reaching conclusions from the present results are also limited by the lack of longer-term and recovery data. Future studies are needed to gain an even more complete picture of the transient cardiovascular responses to the experience of humor.

Taken together, the findings of the present study demonstrated, first, that the experience of amusement is associated with sympathetically driven cardiac activation.

Contrary to widespread beliefs, there is no indication that these effects might produce any immediate health benefits. Second, the transient cardiovascular effects of amusement do not correspond to those of a habitual positive affect disposition reported in the literature. It has been shown, for instance, that a habitual positive affect disposition is associated with a lower ambulatory heart rate and blood pressure and enhanced parasympathetic cardiac control, that is, effects that are opposite to those observed in the present study and beneficial (Steptoe et al. 2009; Bhattacharyya et al. 2008). Thus, the present findings suggest that it would be erroneous to argue from the reported long-term effects of a positive affect disposition to already beneficial effects of a single amusing event. Third, the present study does not provide any evidence for the notion that the intentional suppression of affect might be unfavorable and maladaptive because it might be associated with additionally increased sympathetic nervous system activity, at least as positive affect is concerned.

Acknowledgments The authors would like to thank James J. Gross and Andrea C. Samson from the Stanford University for providing the stimulation material and supporting the conduction of the experiment. Helmut K. Lackner was supported by the Bank Austria Visiting Scientists Program-outgoing.

Conflict of interest None declared.

References

Alexander, R. (1939). Psychological aspects of medicine. *Psychosomatic Medicine, 1*, 7–18.

Bhattacharyya, M. R., & Steptoe, A. (2011). Mood and transient cardiac dysfunction in everyday life. *Journal of Behavioral Medicine, 34*, 74–81.

Bhattacharyya, M. R., Whitehead, D. L., Rakhit, R., & Steptoe, A. (2008). Depressed mood, positive affect, and heart rate variability in patients with suspected coronary artery disease. *Psychosomatic Medicine, 70*, 1020–1027.

Brennan, M., Palaniswami, M., & Kamen, P. (2001). Do existing measures of Poincare plot geometry reflect nonlinear features of heart rate variability? *IEEE Transactions on Biomedical Engineering, 48*, 1342–1347.

Brosschot, J. F., & Thayer, J. F. (2003). Heart rate response is longer after negative emotions than after positive emotions. *International Journal of Psychophysiology, 50*, 181–187.

Chida, Y., & Hamer, M. (2008). Chronic psychosocial factors and acute physiological responses to laboratory-induced stress in healthy populations: A quantitative review of 30 years of investigations. *Psychological Bulletin, 134*, 829–885.

Cysarz, D., von Bonin, D., Lackner, H., Heusser, P., Moser, M., & Bettermann, H. (2004). Oscillations of heart rate and respiration synchronize during poetry recitation. *American Journal of Physiology-Heart and Circulatory, Physiology, 287*, H579–H587.

Davidson, K. W., Mostofsky, E., & Whang, W. (2010). Don't worry, be happy: Positive affect and reduced 10-year incident coronary heart disease: The Canadian Nova Scotia Health Survey. *European Heart Journal, 31*, 1065–1070.

Demaree, H. A., Robinson, J. L., Pu, J., & Allen, J. J. B. (2006). Strategies actually employed during response-focused emotion regulation research: Affective and physiological consequences. *Cognition and Emotion, 20*, 1248–1260.

Dockray, S., & Steptoe, A. (2010). Positive affect and psychobiological processes. *Neuroscience and Biobehavioral Reviews, 35*, 69–75.

Duclos, S. E., Laird, J. D., Schneider, E., Sexter, M., Stern, L., & vanLighten, O. (1989). Emotion-specific effects of facial expressions and postures of emotional experience. *Journal of Personality and Social Psychology, 57*, 100–108.

Dunn, B. D., Billotti, D., Murphy, V., & Dalgleish, T. (2009). The consequences of effortful emotion regulation when processing distressing material: A comparison of suppression and acceptance. *Behaviour Research and Therapy, 47*, 761–773.

Ernst, J. M., Litvack, D. A., Lozano, D. L., Cacioppo, J. T., & Berntson, G. G. (1999). Impedance pneumography: Noise as signal in impedance cardiography. *Psychophysiology, 36*, 333–338.

Fortin, J., Habenbacher, W., Heller, A., Hacker, A., Grüllenberger, R., Innerhofer, J., et al. (2006a). Non-invasive beat-to-beat cardiac output monitoring by an improved method of transthoracic bioimpedance measurement. *Computers in Biology and Medicine, 36*, 1185–1203.

Fortin, J., Marte, W., Grüllenberger, R., Hacker, A., Habenbacher, W., Heller, A., et al. (2006b). Continuous non-invasive blood pressure monitoring using concentrically interlocking control loops. *Computers in Biology and Medicine, 36*, 941–957.

Fredrickson, B. L., Mancuso, R. A., Branigan, C., & Tugade, M. M. (2000). The undoing effect of positive emotions. *Motivation and Emotion, 24*, 237–258.

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology, 2*, 271–299.

Gross, J. J., & Levenson, R. W. (1993). Emotional suppression: Physiology, self-report, and expressive behavior. *Journal of Personality and Social Psychology, 64*, 970–986.

Gross, J. J., & Levenson, R. W. (1997). Hiding feelings: The acute effects of inhibiting negative and positive emotion. *Journal of Abnormal Psychology, 106*, 95–103.

Herring, D. R., Burleson, M. H., Roberts, N. A., & Devine, M. J. (2011). Coherent with laughter: Subjective experience, behavior, and physiological responses during amusement and joy. *International Journal of Psychophysiology, 79*, 211–218.

Houtveen, J. H., Groot, P. F., & deGeus, E. J. (2006). Validation of the thoracic impedance derived respiratory signal using multilevel analysis. *International Journal of Psychophysiology, 59*, 97–106.

Kim, S. H., & Hamann, S. (2007). Neural correlates of positive and negative emotion regulation. *Journal of Cognitive Neuroscience, 19*, 776–798.

Kunzmann, U., Kupperbusch, C. S., & Levenson, R. W. (2005). Behavioral inhibition and amplification during emotional arousal: A comparison of two age groups. *Psychology and Aging, 20*, 144–158.

Lackner, H. K., Papousek, I., Batzel, J. J., Roessler, A., Scharfetter, H., & Hinghofer-Szalkay, H. (2011). Phase synchronization of hemodynamic variables and respiration during mental challenge. *International Journal of Psychophysiology, 79*, 401–409.

Lackner, H. K., Weiss, E. M., Schulter, G., Hinghofer-Szalkay, H., Samson, A. C., & Papousek, I. (2013). I got it! Transient cardiovascular response to the perception of humor. *Biological Psychology, 93*, 33–40.

Lahiri, M. K., Kannankeril, P. J., & Goldberger, J. J. (2008). Assessment of autonomic function in cardiovascular disease. *Journal of the American College of Cardiology, 51*, 1725–1733.

Levenson, R. W., Ekman, P., & Friesen, W. V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology, 27*, 363–384.

Mak, A. K. Y., Hu, Z., Zhang, J. X., Xiao, Z., & Lee, T. M. C. (2009). Neural correlates of regulation of positive and negative emotions: An fMRI study. *Neuroscience Letters, 457*, 101–106.

Martin, R. A. (2001). Humor, laughter, and physical health: Methodological issues and research findings. *Psychological Bulletin, 127*, 504–519.

Mittleman, M. A., Maclure, M., Sherwood, J. B., Mulry, R. P., Tofler, G. H., Jacobs, S. C., et al. (1995). Triggering of acute myocardial infarction onset by episodes of anger. *Circulation, 92*, 1720–1725.

Miyazaki, T., & Zipes, D. (1990). Pericardial prostaglandin biosynthesis prevents the increased incidence of reperfusion-induced ventricular fibrillation produced by efferent sympathetic stimulation in dogs. *Circulation, 82*, 1008–1019.

Moertl, M. G., Lackner, H. K., Papousek, I., Roessler, A., Hinghofer-Szalkay, H., Lang, U., et al. (2013). Phase synchronization of hemodynamic variables at rest and after deep breathing measured during the course of pregnancy. *PLoS ONE, 8*, e60675.

Neumann, S. A., & Waldstein, S. R. (2001). Similar patterns of cardiovascular response during emotional activation as a function of affective valence and arousal and gender. *Journal of Psychosomatic Research, 50*, 245–253.

Papousek, I., Paechter, M., & Lackner, H. K. (2011). Delayed psychophysiological recovery after self-concept-inconsistent negative performance feedback. *International Journal of Psychophysiology, 82*, 275–282.

Papousek, I., & Schulter, G. (2010). Don't take an X for a U. Why laughter is not the best medicine, but being more cheerful has many benefits. In I. E. Wells (Ed.), *Psychological well-being* (pp. 1–75). Hauppauge, NY: Nova Science Publishers.

Pressman, S. D., & Cohen, S. (2005). Does positive affect influence health. *Psychological Bulletin, 131*, 925–971.

Roberts, N. A., Levenson, R. W., & Gross, J. J. (2008). Cardiovascular costs of emotion suppression cross ethnic lines. *International Journal of Psychophysiology, 70*, 82–87.

Rosenblum, M. G., Pikovsky, A., & Kurths, J. (2004). Synchronization approach to analysis of biological systems. *Fluctuation and Noise Letters, 4*, 53–62.

Ruch, W. (Ed.). (1998). *The sense of humor: Explorations of a personality characteristic*. Berlin: Mouton de Gruyter.

Sakuragi, S., Sugiyama, Y., & Takeuchi, K. (2002). Effects of laughing and weeping on mood and heart rate variability. *Journal of Physiological Anthropology and Applied Human Science, 21*, 159–165.

Samuels, M. A. (2007). The brain-heart connection. *Circulation, 116*, 77–84.

Schaefer, C., Rosenblum, M. G., Abel, H. H., & Kurths, J. (1999). Synchronization in the human cardiorespiratory system. *Physical Review, E60*, 857–870.

Sloan, R. P., Shapiro, P. A., Bagiella, E., Myers, M. M., & Gorman, J. M. (1999). Cardiac autonomic control buffers blood pressure variability responses to challenge: A psychophysiologic model of coronary artery disease. *Psychosomatic Medicine, 61*, 58–68.

Stein, P. K., Domitrovich, P. P., Huikuri, H. V., & Kleiger, R. E. (2005). Traditional and nonlinear hear rate variability are each independently associated with mortality after myocardial infarction. *Journal of Cardiovascular Electrophysiology, 16*, 13–20.

Steptoe, A., Dockray, S., & Wardle, J. (2009). Positive affect and psychobiological processes relevant to health. *Journal of Personality, 77*, 1747–1775.

Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology, 54*, 768–777.

Strike, P. C., & Steptoe, A. (2005). Behavioral and emotional triggers of acute coronary syndromes. A systematic review and critique. *Psychosomatic Medicine, 67*, 179–186.

Sugawara, J., Tarumi, T., & Tanaka, H. (2010). Effect of mirthful laughter on vascular function. *The American Journal of Cardiology, 106*, 856–859.

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation, 93*, 1043–1065.

Taylor, J. A., & Eckberg, D. L. (1996). Fundamental relations between short-term RR interval and arterial pressure oscillations in humans. *Circulation, 93*, 1527–1532.