Alterations in electrodermal activity and cardiac parasympathetic tone during hypnosis

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Author Note

The study was funded by the Hungarian Scientific Research Funds (K109187 and K100845).

Manuscript accepted for publication in Psychophysiology on October 4, 2015.

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Abstract

Exploring autonomic nervous system (ANS) changes during hypnosis is critical for understanding the nature and extent of the hypnotic phenomenon and for identifying the mechanisms underlying the effects of hypnosis in different medical conditions. To assess ANS changes during hypnosis, electrodermal activity (EDA), and pulse rate variability (PRV) were measured in 121 young adults. Participants either received hypnotic induction (hypnosis condition) or listened to music (control condition), and both groups were exposed to test-suggestions. Blocks of silence and experimental sound stimuli were presented at baseline, after induction and after de-induction. Skin conductance level (SCL) and high frequency (HF) power of PRV measured at each phase were compared between groups. Hypnosis decreased SCL compared to the control condition, however, there were no group differences in HF power. Furthermore, hypnotic suggestibility did not moderate ANS changes in the hypnosis group. These findings indicate that hypnosis reduces tonic sympathetic nervous system activity, which might explain why hypnosis is effective in the treatment of disorders with strong sympathetic nervous system involvement, such as rheumatoid arthritis, hot flashes, hypertension and chronic pain. Further studies with different control conditions are required to examine the specificity of the sympathetic effects of hypnosis.

Keywords: Hypnosis, Autonomic Nervous System, Hypnotic suggestibility, Electrodermal Activity, Heart Rate Variability

Alterations in electrodermal activity and cardiac parasympathetic tone during hypnosis

Hypnosis is defined as a state of consciousness involving focused attention and reduced peripheral awareness characterized by an enhanced capacity for response to suggestion (Elkins, Barabasz, Council, & Spiegel, 2015). Hypnosis is induced using hypnotic induction, which usually involves suggestions for focusing attention (for an overview of different induction techniques see Weitzenhoffer, 1989). In hypnotherapy, hypnosis induction is usually followed by suggestions for the achievement of the therapeutic goal. Suggestions are elements of interpersonal communication, ranging from direct instructions to subtle metaphors, which evoke automatic responses. For example, the suggestion, that there is a heavy object in the subject's hand might evoke a sense of heaviness in the extended arm and an automatic response of lowering of the arm. There are large individual differences in the extent to which a person is able to experience hypnosis. This ability is called hypnotic suggestibility.

Studies have already identified a well-defined pattern of neurophysiological changes evoked by hypnosis in highly hypnotizable subjects. These changes include increased frontal theta and alpha power (Jamieson & Burgess, 2014; Sabourin, Cutcomb, Crawford, & Pribram, 1990; Terhune, Cardeña, & Lindgren, 2011), and increased beta2, beta3 and gamma power in EEG coupled with a reduced global functional connectivity during hypnotic imagery (Cardeña, Jönsson, Terhune, & Marcusson-Clavertz, 2013). Recent investigations also confirmed that hypnosis is associated with increased activity in the prefrontal attentional system - in particular the right middle frontal gyrus, and bilaterally the inferior frontal gyrus and the precentral gyrus; furthermore, decreased activation of the 'default mode network' (DMN), including cortical midline structures of the left medial frontal gyrus, right anterior cingulate gyrus, bilateral posterior cingulate gyri, and bilateral parahippocampal gyri (Deeley et al., 2012; McGeown,

Mazzoni, Venneri, & Kirsch, 2009). Establishing the neurophysiological effects of hypnosis in a neutral resting state set the stage for new research that apply hypnotically induced cognitive, behavioral and emotional phenomenon. This new generation of studies investigates the brain mechanisms underlying attention, motor control, agency, different phenomenological states and clinical conditions (Kihlstrom, 2013; Lifshitz, Cusumano, & Raz, 2014; Oakley & Halligan, 2013).

Similarly, a large body of evidence has accumulated on the benefits of hypnosis in the treatment of various medical illnesses (Kekecs & Varga, 2013; Pinnell & Covino, 2000). Hypnotherapy seems to be particularly effective in the treatment of disorders associated with sympathetic nervous system impairment, such as rheumatoid arthritis (Horton-hausknecht, Mitzdorf, & Melchart, 2000), hot flashes (Elkins et al., 2008), hypertension (Gay, 2007), and chronic pain (Elkins, Jensen, & Patterson, 2007). Meanwhile, there is still much debate regarding the effects of hypnosis on the autonomic nervous system (ANS). Understanding ANS changes during hypnosis may provide a critical link between the CNS and physiological changes elicited by hypnosis. It might also help to understand the mechanisms underlying hypnotherapy's medical benefits. Furthermore, changes in ANS during hypnosis might reveal whether hypnosis exerts its physiological effects mainly through the relaxation response elicited by the position of the body, lack of movement, eye closure, and silent environment; or if it has other specific psychophysiological characteristics over and above that of relaxation. A clearer understanding of ANS changes during a neutral resting state may enable psychophysiological studies on hypnotically induced emotional and cognitive states.

A number of studies and a recent review argue that hypnosis enhances parasympathetic nervous system (PNS) activity (Aubert, Verheyden, Beckers, Tack, & Vandenberghe, 2009;

Debeneditis, Cigada, Bianchi, Signorini, & Cerutti, 1994; S. G. Diamond, Davis, & Howe, 2007; van der Kruijs et al., 2014; VandeVusse, Hanson, Berner, & White Winters, 2010), which would indicate a relaxation-like effect (Sakakibara, Takeuchi, & Hayano, 1994). This finding, however, was not unequivocally supported (De Pascalis & Perrone, 1996; Gemignani et al., 2000; Hippel, Hole, & Kaschka, 2001; Ray et al., 2000). The conclusions of previous studies for the influence of hypnosis on the sympathetic nervous system (SNS) activity are similarly mixed with some studies showing decreased activity during hypnosis (Aubert et al., 2009; De Pascalis & Perrone, 1996; Debeneditis et al., 1994; Griffiths, Gillett, & Davies, 1989; Gruzelier, Brow, Perry, Rhonder, & Thomas, 1984; Gruzelier & Brow, 1985; Hippel et al., 2001), and studies that did not find decreased SNS activity (M. J. Diamond, 1984; Edmonston Jr, 1968; Gruzelier, Allison, & Conway, 1988).

The disagreement in the reports most likely originates from methodological differences. First of all, studies typically use relaxation-based hypnotic induction. The relaxed state induced by this type of induction might increase PNS activity (Sakakibara et al., 1994). Thus, in order to study hypnosis-specific effects over and above that of relaxation, most studies use a relaxation control condition as baseline. However the length and type of control conditions – and consequently the depth of relaxation – show substantial variation between studies. Therefore some of the results of parasympathetic enhancement can still be attributed to relaxation effects.

Another source of confusion is the multitude of ANS measures used in these studies and their misinterpretation. Several studies assessed autonomic changes using electrodermal activity (EDA) and heart rate variability (HRV) for measuring SNS and PNS activity. While EDA and high frequency power (HF) of the HRV spectrum have a strong standing as a measure for SNS activity and cardiac vagal tone respectively (Billman, 2013; Boucsein et al., 2012; Fowles, 1986;

Lidberg & Wallin, 1981; Malik et al., 1996), the interpretation of other HRV metrics is debated. Specifically, several studies used the low frequency (LF) component of HRV spectrum or the ratio of low frequency and high frequency (LF/HF) power to assess sympathetic nervous system activity and 'sympathetic-parasympathetic balance'. However, LF power seems to be influenced by sympathetic effects, parasympathetic effects, and other non-autonomic factors at the same time (Randall, Brown, Raisch, Yingling, & Randall, 1991), making the interpretation of LF and LF/HF ratio dubious (Billman, 2013). Yet another frequent issue is the separate interpretation of HF and LF expressed in normalized units (n.u.) and the LF/HF ratio, whereas these measures should be considered equivalent carriers of information about sympathovagal balance (Burr, 2007). Therefore, conclusions of previous studies should be treated cautiously. When we re-evaluate previous results focusing only on the most straightforward measures of SNS and PNS (EDA and HF power) we find that there is considerable evidence supporting the decrease of sympathetic activity during hypnosis (Griffiths et al., 1989; Gruzelier et al., 1984; Gruzelier & Brow, 1985). However, findings on the changes in cardiac vagal influence are ambiguous (S. G. Diamond et al., 2007; Hippel et al., 2001; VandeVusse et al., 2010). Thirdly, most of the above mentioned studies have a low sample size, which raise the question whether some of the effects remained undetected because of lack of statistical power.

A possible confounding factor for ANS response during hypnosis is hypnotic suggestibility. There is some evidence for the moderating effect of hypnotic suggestibility on ANS changes during hypnosis (Debeneditis et al., 1994; Gruzelier et al., 1984; Gruzelier & Brow, 1985) as well as in waking state (Harris, Porges, Clemenson, & Vincenz, 1993; Jorgensen & Zachariae, 2002; Santarcangelo et al., 2012). However, most studies do not control for this

variable, or only focus on the extremes of the spectrum ([Aubert et al., 2009](#); [S. G. Diamond et al., 2007](#); [Gemignani et al., 2000](#); [Yüksel, Ozcan, & Dane, 2013](#)).

The aim of the present study was to clarify our understanding of ANS changes in response to hypnosis. Keeping in mind shortcomings of previous research, we used a relatively large sample size, behaviorally matched control condition, based our interpretations on the most established measures of SNS and PNS activity (EDA and HF power), and took into account participants' hypnotic suggestibility. Based on the re-evaluation of previous research findings, we hypothesized that hypnosis decreases EDA tone more than a non-hypnotic relaxed state. We also wanted to assess whether hypnosis has an effect on HF power compared to relaxation, to clarify previous contradictory reports on PNS changes elicited by hypnosis. Moreover, we expected the level of hypnotic suggestibility to be positively correlated with the ANS changes during hypnosis.

Methods

Participants

121 adults participated in the study (72% females, age range = 18-46 years, mean age = 21.64 ± 3.82 years). The study was conducted in accordance with the guidelines of the Declaration of Helsinki, and Universitythe Research Ethics Committee of the Institute of Psychology, Eötvös Loránd University, approved the research plan. None of the participants received monetary compensation for taking part in the study. Exclusion criteria were any psychiatric or neurological illnesses, and present use of hypnotic, sedative, or anxiolytic medication based on self-report. Previous experience with hypnosis was also noted during baseline inquiry. 93% of the participants in the hypnosis group and 91% in the control group had

no previous hypnosis experience before. The difference in the distribution of participants with and without prior hypnosis experience is not significant between the groups (Fisher's Exact Test $p > 0.999$).

Study design

Experimental sessions started at 9 a.m. or 11:30 a.m. and lasted approximately 90 minutes with 5 – 13 participants attending each session. During a 15 minutes waiting period, participants provided informed consent and were fitted with measurement sensors. Subsequently participants were randomized to listen to one of two procedures from audiotape: either the Waterloo-Stanford Group C (WSGC) protocol of hypnotic suggestibility ([Bowers, 1993](#)) (hypnosis group), or a version of the same procedure in which hypnotic induction and de-induction were replaced by music (control group). Both groups were exposed to three blocks of experimental sound stimuli presented at baseline, post-induction and post-de-induction. (The experimental design is displayed in Figure 1.) Electrodermal activity and inter-beat interval were recorded during the experimental blocks. Participants were not specifically informed about their group allocation, but it became apparent at the induction phase when they received either hypnosis induction or music.

Figure 1. Experimental design

During the procedure, the hypnosis group listened to the hypnotic induction, test-suggestions and de-induction of the Waterloo-Stanford Group Hypnosis protocol, while the control group received music instead of hypnotic induction and de-induction, but listened to the same test-suggestions. Experimental blocks (120-second each) were presented at baseline, after induction and after de-induction. Experimental blocks started with 30-second of silence followed by 12 standard and 2 deviant sound stimuli presented with 5-7 stimulus onset interval in an auditory oddball paradigm.

Instrument

Procedure. Waterloo-Stanford Group C ([Bowers, 1993](#)) is a standardized scale to measure hypnotic suggestibility. The scale includes hypnotic induction by eye closure and relaxation followed by twelve test-suggestions and de-induction.

During the induction (lasting about 12 minutes), subjects are asked to focus their attention on a spot on their hands and on the voice of the hypnotherapist. While they are staring at the spot for several minutes, they get suggestions that their eyelids will feel heavy, that they will feel sleepy, and that as their eyes slowly close, they will gradually go into hypnosis. The eye

closure is followed by deepening of hypnosis with counting numbers from 1 to 20 accompanied by several suggestions of going deeper and deeper into hypnosis. During the de-induction (approximately 1.5 minutes), subjects are prompted to gradually awaken while the hypnotherapist counts backwards from 20 to 1. During the countdown, they get additional suggestions for getting awake and alert.

Between the induction and de-induction, subjects are presented with test-suggestions. Hypnotic suggestibility is determined from the subject's self-report of her responsiveness to these test-suggestions. For example, one of the test-suggestions consists of suggestions for the subject to feel her arm so heavy, that it is too heavy to lift, after which the subject is asked to try to lift her arm. Following de-induction, the subject completes a post-hypnosis questionnaire, in which she is asked whether she was able to raise the arm or not. If she indicates that she was unable to lift her arm, she "passed" the test-suggestion, meaning that the suggestions evoked the intended automatic response. The post-hypnosis questionnaire contains similar questions for each of the test-suggestions. One point is scored for each test-suggestion passed. Internal consistency of WSGC ranges between .77 and .80 (Bowers, 1998; Kirsch, Milling, & Burgess, 1998).

To reduce movement artifacts, test-suggestions were modified so that tasks were performed using the dominant hand only, while EDA sensors were placed on the resting non-dominant hand. Test-suggestions 'Moving Hands Together' and 'Age Regression' were omitted from the protocol because they involve both hands. The 'Negative Visual Hallucination' was also removed from the script to avoid artifacts resulting from the opening of the eyes.

This modified version of WSGC, containing only nine tests suggestions, was audio recorded by a hypnotherapist (third author, KV), and allowed for the assessment of hypnotic

suggestibility on a scale of 0 to 9. Another version of the recording was also created, in which the induction and de-induction were replaced by a music compilation. The compilation was comprised of music from diverse genres to control for genre preference. The music replacing the de-induction was fast paced and alerting in nature, to match the re-alerting purpose of the de-induction. The feasibility of this control condition was tested in a prior study (unpublished). In that study, the musical pieces were selected to match the flow of the hypnosis induction and de-induction process. The purpose of playing music was to give sound stimulation to the participants in which they can absorb while relaxing, to avoid boredom, and at the same time avoiding the focused attention on one human voice, which might elicit hypnosis-like effects. Details on the music compilation can be found in Supplement 1. The hypnosis group listened to the recording with the hypnosis-induction and de-induction intact, while the music group listened to the version with these replaced by music. Every other procedure was the same across groups, leaving the presence or absence of hypnosis induction as the only experimental difference. During all the sessions the same trained hypnotherapist (third author, KV) supervised the procedure.

Experimental blocks. Blocks of sound stimuli were presented three times during the study session to both groups. Audio was delivered through Videoton stereo speakers connected to a Sanyo JA 220 amplifier at 70dB SPL. Experimental blocks started with 30 seconds of silence, followed by sound stimuli organized according to an auditory oddball paradigm, consisting of twelve ‘standard’ stimuli (1000 Hz tones) and two ‘deviant’ stimuli (animal sounds) in random order and with random stimulus onset intervals (SOI) of 5–7 seconds. Accordingly, each experimental block lasted for approximately 120 seconds. (The purpose of the sound stimuli was to study event-related electrodermal responses under hypnosis. Results on skin conductance

orientation responses will not be presented here because the paper focuses on the effects of hypnosis on ANS tone.) Later analyses revealed that group effects on ANS are not significantly different between the first 30-second long silence period and the subsequent period containing the sound stimuli, therefore we use the data extracted from the entire 120-second long experimental block in our analyses. Participants were exposed to the experimental blocks at baseline, post-induction and post-de-induction, while they were sitting still with eyes closed.¹ The sound stimuli blocks were referred to as ‘calibration of the measurement equipment’ by the hypnotherapist on the recording. Participants were instructed to sit with their eyes closed and relax while the calibration took place, and no task was administered during the experimental blocks.

Equipment and data acquisition

Electrodermal activity and blood volume pulse waveform was monitored using OpenEDA (Maruzsa, Köteles, & Szekely, 2015), an open source bio-monitor with 4Hz and 100Hz sampling rate respectively. Detailed description of the device is available at <http://www.affektiv.hu/doku.php?id=openeda>.

For electrodermal measurements Skintact FS-RG1 disposable Ag/AgCl electrodes (Leonhard Lang GmbH, Innsbruck, Austria) were used with a solid gel electrolyte. At the beginning of the 15 minute waiting period electrodermal electrodes were attached to the volar surface of the medial phalanges on the index and middle fingers of the non-dominant hand, while the pulse photoplethysmography (PPG) transducer was clipped to the left earlobe to decrease PPG’s vulnerability to movement artifacts (Barker & Shah, 1997; G. Lu, Yang, Taylor, & Stein, 2009). No pretreatment was used on the recording sites.

¹ The second experimental block (post-induction) was presented at the end of the ‘Dream’ test-suggestion, where the hypnotherapist is silent while the subject has a ‘dream about hypnosis’.

Data processing

Electrodermal activity was analyzed using Ledalab 3.4.5 ([Benedek & Kaernbach, 2010](#)). After smoothing with a Gaussian window to decrease error noise, as recommended by Boucsein and colleagues ([2012](#)), EDA time series were visually inspected to detect artifacts. Visually detected artifacts were corrected with Ledalab's artifact correction tool using spline interpolation ([Benedek & Kaernbach, 2010](#)). Subsequently, skin conductance level (SCL) was determined through optimized Continuous Decomposition Analysis ([Benedek & Kaernbach, 2010](#)). SCL corresponds to the tonic activity of the SNS. SCL was extracted in consecutive five second epochs during the experimental blocks resulting in a total number of 24 data points for each experimental block. SCLs were standardized within each individual using the `ztransform()` function in R, and were rank transformed to achieve normality (log and square-root transformation did not achieve normal distribution) ([Bach, Flandin, Friston, & Dolan, 2009](#); [Boucsein et al., 2012](#); [Braithwaite, Watson, Jones, & Rowe, 2013](#)). According to Venables and Michelle ([Venables & Mitchell, 1996](#)), around 25% of the normal population are EDA non-responders to orientation stimuli (such as stimuli used in our present study). In the present study participants who did not show a detectable skin conductance responses determined by the Continuous Decomposition Analysis to any of the first four 'standard' sound stimuli presented at baseline were identified as non-responders and were dropped from EDA analysis. In total, the electrodermal data of 33 participants was omitted from analysis (six because of faulty equipment, seven due to the disconnection of the EDA electrode during the session, and 20 participants [18 %] who were identified as non-responders).

Pulse waveform was analyzed to obtain pulse rate variability (PRV). PRV is shown to be a good surrogate of HRV when used in a resting state with young participants ([Charlot, Cornolo,](#)

Brugniaux, Richalet, & Pichon, 2009; Gil et al., 2010; G. Lu et al., 2009; Schäfer & Vagedes, 2013; Selvaraj, Jaryal, Santhosh, Deepak, & Anand, 2008). Inter Beat Intervals (IBIs) indicating the time between two heartbeats were automatically extracted from the blood volume pulse waveform by OpenEDA using an adaptive threshold algorithm. Artifacts were detected via an individually calculated threshold criterion derived from the IBI distributions (Berntson, Quigley, Jang, & Boysen, 1990; Berntson & Stowell, 1998) and were corrected using a cubic spline interpolation, followed by frequency domain analysis via ARTiiFACT 2.09 (Kaufmann, Sütterlin, Schulz, & Vögele, 2011). Cases with higher than 10% of data points identified as artifacts were dropped from analysis. The data from 10 participants' PRV was dropped from analysis (four due to the disconnection of the PPG sensor and six because of more than 10% of the data points were artifacts). Spectral frequency measures were derived using fast fourier transformation with 0.15–0.4 Hz frequency bands set for HF as recommended by the Task Force of the European Society of Cardiology (Malik et al., 1996) and were expressed in absolute power [ms^2]. HF was expressed in absolute units instead of normalized units (n.u.) because HF n.u. is a measure of sympatho-vagal balance instead of a clear measure of parasympathetic activity (Burr, 2007). PRV data was normalized via log-transformation.

Statistical analysis

SCL and PRV data were submitted to a mixed model analysis². For both SCL and PRV, fixed effects were Group (hypnosis vs. music) $\times$ the quadratic term of Phase (baseline vs. post-induction vs. post-de-induction), to see if there were any group differences manifesting in the post-induction phase but not before and after.

² Mixed model is a type of regression model containing both fixed effects and random effects. They are particularly useful when repeated measurements are made or with other types of interrelations in the dataset.

The hypnotic suggestibility assessment was completed in both groups; however, the control group was not exposed to hypnosis induction. This way, participants of the control group did not have a valid hypnotic suggestibility score, so the moderating effect of hypnotic suggestibility was only tested in the hypnosis group. For both SCL and PRV, fixed effects were the quadratic term of Phase (baseline vs. post-induction vs. post-de-induction) $\times$ Hypnotic suggestibility (entered as a continuous variable).

To account for intercorrelation of repeated measures within individuals, subject ID was included as a random effect parameter in all models. Study session ID (date and time of the session) was also identified as a possible random effect parameter to control for differences in temperature and ambient noise. To avoid over-parameterization, a sequence of models were fit with gradually decreasing complexity of the random effect structure (Baayen, Davidson, & Bates, 2008), with the most complex model being a full random slope model with both Subject ID and Session as random effects, and the most simple model being a random intercept model with only Subject ID as a random effect. The model with the optimal model complexity characterized by the lowest Akaike Information Criterion (AIC) index (Akaike, 1987) was retained for the final analyses.

All statistical analyses were performed in lme4 v. 1.1-7, (Bates, Maechler, & Bolker, 2014) and lmerTest v. 2.0-11, (Kuznetsova, Brockhoff, & Christensen, 2014) in R v. 3.1.1.

Results

The EDA data of 88 participants (42 from the hypnosis group) and the PRV data of 111 participants (54 from the hypnosis group) were retained for statistical analysis³. No significant group differences were noted in age and gender or in outcome measures at baseline (see Table 1 and Table 2).

Table 1

Group differences in demographics during baseline assessment

Demographic	Hypnosis group	Control group			
	Mean (SD) or count (percentage)	Mean (SD) or count (percentage)	df	t-value or χ^2	p-value
Age (EDA)	21.21 (2.56)	21.25 (4.31)	74.41	-0.05	.958
Age (PRV)	21.52 (3.30)	21.58 (4.34)	104.15	-0.09	.932
Female (EDA)	26 (61.90%)	35 (76.09%)	1 (N = 88)	1.46	.227
Female (PRV)	35 (64.81%)	44 (77.19%)	1 (N = 111)	1.51	.219

Notes. EDA – electrodermal activity, PRV - pulse rate variability. Statistics of group (hypnosis vs music) differences during baseline. The EDA data of 88 participants (42 from the hypnosis group) and the PRV data of 111 participants (54 from the hypnosis group) were analyzed. No group differences were found in demographic variables.

³ The EDA data of 33 individuals and the PRV data of 10 individuals were omitted from data analysis because of containing too many artifacts, disconnection of electrodes or being EDA non-responders. See Data processing for details. Test statistics reported in the paper were obtained from analyses on this reduced sample, however interpretation of the results remain the same when performing the analyses on the sample including EDA non-responders and individuals with too many artifacts.

Table 2

Group differences in outcomes during baseline assessment

Outcome	Hypnosis group	Control group	Estimate	SE	df	t-value	p-value
	Mean (SD)	Mean (SD)					
SCL	-0.24 (0.93) ^a	-0.34 (1.03) ^a	-0.10	0.16	88	-0.64	.523
HF	6.27 (1.02) ^b	6.61 (1.08) ^b	0.35	0.20	109	1.74	.085

Notes. SCL – skin conductance level, HF - high frequency power of the pulse rate variability.

Statistics of group (hypnosis vs music) differences during baseline. a – SCL data were standardized within each individual and rank-transformed to normality. b - HF data were log-transformed to normality.

No group differences were found in SCL or HF at baseline.

The effect of procedure and group

Test statistics are summarized in Table 3.

SCL

We found a significant effect of the interaction between Group and the quadratic term of Phase on SCL. As apparent in Figure 2, this result shows that, while the two groups had similar SCLs at baseline and at post-de-induction, SCL was significantly lower post-induction in the hypnosis group compared to the control group. The figure also highlights that SCL decreased in the hypnosis group in result of the hypnosis induction, while it did not substantially change in the control group after the control-induction.

Figure 2. Effect of hypnosis on skin conductance level

White

disks and gray triangles represent regression coefficients of the Z and rank transformed skin conductance level of the hypnosis and the control group respectively by study phase (baseline, post-induction, post-de-induction). Y error bars display 1.96 Standard Errors. * $p < .05$.

Hypnotic induction resulted in an SCL decrease compared to baseline, while no such change was observed after listening to music.

HF power

The effect of the interaction of the quadratic term of Phase and Group was not significant on HF power. This finding provides no support for hypnosis-specific alterations in HF.

Table 3

The effect of procedure and group

Outcome ~ Fixed effect	Estimate	SE	df	t-value	p-value
SCL ~ Phase (quadratic) × Group	-0.40	0.13	189.27	-2.97	.004
HF ~ Phase (quadratic) × Group	-0.06	0.08	222	-0.70	.482

Notes. SCL – skin conductance level, HF - high frequency power of the pulse rate variability.

SCL was decreased post-induction in the hypnosis group, but not the music group. No group differences were observed in the change of HF post-induction.

The effect of hypnotic suggestibility

No two-way interaction was found between the quadratic term of Phase and hypnotic suggestibility on either SCL or HF, implying that the effect of hypnosis on the ANS is not moderated by susceptibility to hypnotic suggestions.

Table 4

<i>The moderating effect of hypnotic suggestibility on the effect of the procedure</i>						
Outcome ~ Fixed effect	Estimate	SE	df	t-value	p-value	
SCL ~ Phase (quadratic) × Hypnotic suggestibility	0.04	0.06	52.48	0.69	.494	
HF ~ Phase (quadratic) × Hypnotic suggestibility	0.01	0.03	108	0.24	.814	

Notes. SCL – skin conductance level, HF - high frequency power of the pulse rate variability.

Hypnotic suggestibility did not moderate the ANS effects of the procedure.

Discussion

In the present study we examined ANS changes in response to hypnotic induction or a control condition (induction replaced by music), by using electrodermal activity and pulse rate variability. Furthermore, we explored the possible moderating effect of hypnotic suggestibility on the ANS responses. The hypnosis group showed a decrease in average tonic EDA from baseline to post-induction, while EDA did not change in the control. However, no group differences were found in HF power of pulse rate variability.

In line with our hypotheses, lower tonic electrodermal activity was found in the hypnosis compared to the control group post-induction, indicating that hypnosis decreases sympathetic nervous system activity relative to rest induced by music. Group differences in SNS activity were found even though groups were matched in body position, amount of movements, eye closure and auditory environment, suggesting that this effect cannot be solely attributed to physical relaxation and lack of environmental stimuli. Neither can it be a product of the test-suggestions, which were also matched between groups. Rather, the effective component lies in hypnotic induction.

The existence and uniqueness of a 'hypnotic state' and whether hypnotic induction is a particularly important component in eliciting hypnotic effects are subjects to heated debate (Kihlstrom, 1997; Kirsch, 2011; Lynn, Fassler, & Knox, 2005; Mazzoni, Venneri, McGeown, & Kirsch, 2013). Recent studies confirm that hypnosis elicits unique neurophysiological and functional changes, such as increased theta and alpha power in the frontal regions (Jamieson & Burgess, 2014; Sabourin et al., 1990; Terhune et al., 2011), and increased beta2, beta3 and gamma power together with decreased global functional connectivity (Cardeña et al., 2013).

Imaging studies also show increased activity in the prefrontal attentional system coupled with a decreased activation of the DMN, including the anterior cingulate cortex (ACC) ([Deeley et al., 2012](#); [McGeown et al., 2009](#)), but see ([Demertzi et al., 2011](#)). For a review on the neuropsychology of hypnosis, see ([Vanhaudenhuyse, Laureys, & Faymonville, 2014](#)). Our present findings provide additional evidence in favor of hypnotic induction being able to elicit physiological responses that are qualitatively different from relaxation. However, it is noteworthy that most of the above cited studies found interaction with individual differences in hypnotic responsiveness, while in our study; hypnotic suggestibility did not influence the SNS effects of hypnosis.

Particularly interesting are findings showing decreased activation of the ACC while resting in hypnosis compared to normal rest ([Deeley et al., 2012](#); [McGeown et al., 2009](#)), as neuroimaging and clinical evidence both indicate, that this structure is closely involved in sympathetic regulation. Enhanced activation of the ACC was shown to increase sympathetic control of heart rate, while patients with ACC lesions had an impaired sympathetic response to both low-level autonomic, behavioral and cognitive stimulation ([Critchley et al., 2003](#)). Other studies found a positive correlation of ACC activity and EDA, and a lack of electrodermal responsiveness in patients with ACC lesions ([Critchley, Melmed, Featherstone, Mathias, & Dolan, 2001](#); [Fredrikson et al., 1998](#); [Tranel & Damasio, 1994](#)). Furthermore, frontal midline theta activity, thought to be generated by the alternating activation of prefrontal cortex and ACC, was also shown to be connected to sympathetic control ([Kubota et al., 2001](#); [Takahashi et al., 2005](#)). These findings may provide a link between the CNS and ANS changes found in hypnosis, making it probable, that the reduced sympathetic tone found in our study was mediated by the inhibition of the ACC in hypnosis. This might be a compelling theory for a neutral, resting state

in hypnosis while the subject is only passively observing stimuli, however we have to be cautious in generalizing this theory to hypnosis as a whole. Findings indicate that the ACC increases activity in response to hypnosis induction with suggestions for analgesia, or paralysis, or with instructions to recall pleasant autobiographic memories ([Vanhaudenhuyse et al., 2014](#)). Simultaneous monitoring of ACC and sympathetic activity before and after different hypnosis induction techniques and different suggestion content might provide a clearer picture of the mediating role of the cingulate cortex in the SNS changes in hypnosis.

Hypnosis induction is not the only event that results in reduced sympathetic tone. Decreased sympathetic arousal compared to resting baseline is also reported after changes in cognitive or emotional states, such as boredom ([Merrifield & Danckert, 2014](#); [Pattyn, Neyt, Henderickx, & Soetens, 2008](#)) or sadness ([Kunzmann & Grühn, 2005](#); [Marsh, Beauchaine, & Williams, 2008](#)), and especially high number of studies show decreased SNS activity during shifts to positive emotional states such as contentment, moderate joy or amusement ([Christie & Friedman, 2004](#); [Kreibig, 2010](#); [Kreibig, Samson, & Gross, 2013](#); [Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000](#)). Thus, it is possible, that some of the SNS changes observed in hypnosis are partly explained by the emotional shift toward joy or amusement, although this is probably less prevalent in a standard laboratory hypnosis session such as the one used in our study. More research is needed to clarify the role of emotional states in sympathetic effects of hypnosis, in both laboratory and therapeutic contexts.

Contrary to our hypothesis, the changes observed in SNS activity due to hypnosis induction were not influenced by hypnotic suggestibility. The fact that the sympathetic changes due to hypnosis were observed with similar strength across the hypnotic suggestibility spectrum raise the possibility that the effect is not a truly hypnosis-specific effect, rather, is a result of

some non-specific component of the induction technique ([Woody, 1997](#)). Accordingly, there have been indications that other mind-body practices such as Thai Chi ([W.-A. Lu & Kuo, 2003](#); [Motivala, Sollers, Thayer, & Irwin, 2006](#)), Yoga ([Bower et al., 2014](#)), meditation ([Delmonte, 1985](#); [Kunzmann & Grünh, 2005](#); [Takahashi et al., 2005](#); [Walton, Pugh, Gelderloos, & Macrae, 1995](#)), and recitation of rosary prayer or yoga mantras ([Bernardi et al., 2001](#)) decreased the activity of the SNS. Specifically, both Thai Chi Chih and meditation was found to acutely reduce SNS activity compared to passive rest ([Motivala et al., 2006](#); [Takahashi et al., 2005](#)), thus, producing a very similar effect to the one found in our research. We have to note that there is a lack of empirical research on the effects of different types of meditation on the ANS. It is possible that different types of meditation evoke differential ANS effects, and the same might be true for different types of hypnosis inductions or hypnosis interventions with different suggestions. Contrasting CNS and ANS changes between hypnosis and these different types of practices might yield important insight into the underlying mechanisms, and the similarities and differences of the ways by which these techniques assert their effects. These studies could also clarify, whether the SNS change found in our present investigation is a result of a non-specific components of hypnosis induction (such as expectancy), or a more specific component also present in the above mentioned techniques, such as internally focused attention.

Regardless of specificity, our findings can offer a possible explanation for the effectiveness of hypnotherapy in treating medical disorders. Hypnosis is used as a mind-body therapy that is highly effective in the treatment of somatic disorders such as autoimmune diseases ([Horton-hausknecht et al., 2000](#)), hot flashes ([Elkins et al., 2008](#)), hypertension ([Gay, 2007](#)), and chronic pain ([Elkins et al., 2007](#)). A common characteristic of these diseases is that they are associated with dysregulation of the sympathetic nervous system ([Crockett & Panickar,](#)

2011; [Dekkers, Geenen, Godaert, Bijlsma, & Van Doornen, 2003](#); [Lipov et al., 2007](#); [Parati & Esler, 2012](#); [Peroutka, 2004](#)). The down-regulation of SNS in hypnosis, verified in our study, might be an integral part of the mechanism governing the beneficial effects of hypnosis (and similar mind-body techniques) in these disorders. More research is warranted to investigate the long-term impact of hypnosis on sympathetic tone in disorders associated with chronic SNS over-activity.

The lack of association between study condition and HF power does not support the concept of increased cardiac vagal control during hypnosis over and above that found in a non-hypnotic relaxation. This finding is in line with the results of [Hippel and Kaschka \(2001\)](#), who conclude that hypnosis reduces sympathetic activity, but has no additional effect on the PNS, when compared to relaxation. Furthermore lack of evidence for PNS effects are consistent with the current consensus of the literature in that hypnotic phenomenon are not simply a product of relaxation ([Oakley & Halligan, 2013](#)) since hypnosis can also be evoked with hypnotic induction during physical exercise, like in active-alert hypnosis ([Bányai & Hilgard, 1976](#)).

Limitations and Future Research

The study also has some limitations. Breathing frequency was not controlled, which might decrease the concordance of HF and cardiac vagal control ([Grossman, Karemaker, & Wieling, 1991](#)). Smoking status, chronic pain, BMI and diabetes were also unmonitored, which might have caused increase in error noise in HRV data. Hypnotic suggestibility data are only available for the hypnosis group (because the control group was not formally hypnotized). This way potential effects of hypnotic suggestibility on between-group differences cannot be examined. Furthermore, as usual in the general population, most subjects were in the medium ranges of hypnotic suggestibility ([Bowers, 1993](#)), and the number of low and high hypnotizables

were relatively small. Thus, results on the lack of effects of hypnotic suggestibility should be interpreted cautiously. Further, the affective effects and appreciation of the music was not monitored, which might have introduced unintended group differences. However, this noise is likely to be minimal due to the time elapsed between the induction and the post-induction measurement point (10 minutes), which is confirmed by the fact that there was no difference between the SCL measured at baseline and at post-induction in the control group.

Future studies should aim for controlling expectancy effects (for example by using sham hypnosis intervention) and number of relaxation instructions in the groups or should use a completely 'neutral' hypnotic induction without any suggestions for relaxation or sleepiness ([Cardena et al., 2013](#)). It would also be interesting to see whether results of this study can be replicated with a different relaxation control condition, for example listening to nature sounds, and whether hypnosis elicited through active-alert induction would produce similar SNS effects compared to a matched exercise control condition.

Conclusion

Recently, there has been a lot of enthusiasm in neuroscience literature about using hypnosis to study brain mechanisms involved in a wide variety of cognitive, behavioral and clinical phenomena ([Kihlstrom, 2013](#); [Lifshitz et al., 2014](#); [Oakley & Halligan, 2013](#)). These applications are made possible by an increased understanding of the neural correlates of hypnosis. To extend these applications to the study of the autonomic nervous system we need to get a clear understanding of the ANS effects of hypnosis in a neutral, relaxed state, so that we have a stable baseline to which additional suggestion-induced effects can be compared. To achieve this goal, our study provided a multi-method examination of autonomic response to hypnosis induction compared to music-induced relaxation.

According to our results, hypnosis decreases sympathetic nervous system tone. However, no hypnosis-specific effect was found within the cardiac parasympathetic tone. These SNS effects might explain hypnosis' niche in the therapy of a variety of somatic disorders with strong sympathetic involvement, such as autoimmune diseases, hot flashes, hypertension, and chronic pain. Further investigation on the long-term effects of hypnosis on sympathetic tone might reveal mechanisms underlying the effectiveness of hypnotic techniques in therapies of somatic illnesses. Future research is also encouraged on the mediating role of the ACC and emotional states in the inhibition of the SNS activity in hypnosis, and on the differential effects of hypnosis and other mind-body techniques such as meditation or Thai Chi Chih.

Acknowledgements

We would like to acknowledge Dorottya Varga, Lili Anna Gönczi, Réka Kassai and Rózsa Katonai for their assistance in organizing study sessions and obtaining data. We are also grateful for Devin Terhune, Eszter Kótyuk, István Czigler and Tamás Nagy for their helpful comments and suggestions on the previous draft of the manuscript.

Disclosures

The study was supported by grants K109187 and K100845 of the Hungarian Scientific Research Funds. The authors have no conflict of interest to report.

References

- Akaike, H. (1987). Factor analysis and AIC. *Psychometrika*, 52(3), 317-332.
doi:10.1007/BF02294359
- Aubert, A. E., Verheyden, B., Beckers, F., Tack, J., & Vandenberghe, J. (2009). Cardiac autonomic regulation under hypnosis assessed by heart rate variability: spectral analysis and fractal complexity. *Neuropsychobiology*, 60(2), 104-112. doi:10.1159/000239686
- Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of memory and language*, 59(4), 390-412.
doi:10.1016/j.jml.2007.12.005
- Bach, D. R., Flandin, G., Friston, K. J., & Dolan, R. J. (2009). Time-series analysis for rapid event-related skin conductance responses. *Journal of neuroscience methods*, 184(2), 224-234. doi:10.1016/j.jneumeth.2009.08.005
- Bányai, É. I., & Hilgard, E. R. (1976). A comparison of active-alert hypnotic induction with traditional relaxation induction. *Journal of Abnormal Psychology*, 85(2), 218-224.
doi:10.1037/0021-843X.85.2.218
- Barker, S. J., & Shah, N. K. (1997). The effects of motion on the performance of pulse oximeters in volunteers (revised publication). *Anesthesiology*, 86(1), 101-108.
doi:10.1097/00000542-199610000-00012
- Bates, D., Maechler, M., & Bolker, B. (2014). lme4: Linear mixed-effects models using Eigen and Eigen++. R package version 1.1-7. Retrieved from <http://cran.r-project.org/web/packages/lme4/>
- Benedek, M., & Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. *Journal of neuroscience methods*, 190(1), 80-91. doi:10.1016/j.jneumeth.2010.04.028

- Bernardi, L., Sleight, P., Bandinelli, G., Cencetti, S., Fattorini, L., Wdowczyk-Szulc, J., & Lagi, A. (2001). Effect of rosary prayer and yoga mantras on autonomic cardiovascular rhythms: comparative study. *Bmj*, 323(7327), 1446-1449.
doi:10.1136/bmj.323.7327.1446
- Berntson, G. G., Quigley, K. S., Jang, J. F., & Boysen, S. T. (1990). An approach to artifact identification: Application to heart period data. *Psychophysiology*, 27(5), 586-598.
doi:10.1111/j.1469-8986.1990.tb01982.x
- Berntson, G. G., & Stowell, J. R. (1998). ECG artifacts and heart period variability: don't miss a beat! *Psychophysiology*, 35(1), 127-132. doi:10.1111/j.1469-8986.2008.00710.x
- Billman, G. E. (2013). The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. *Frontiers in physiology*, 4. doi:10.3389/fphys.2013.00026
- Boucsein, W., Fowles, D., Grimnes, S., Ben-Shakhar, G., Roth, W., Dawson, M., & Filion, D. (2012). Publication recommendations for electrodermal measurements. *Psychophysiology*, 49, 1017–1034. doi:10.1111/j.1469-8986.2012.01384.x
- Bower, J. E., Greendale, G., Crosswell, A. D., Garet, D., Sternlieb, B., Ganz, P. A., . . . Cole, S. W. (2014). Yoga reduces inflammatory signaling in fatigued breast cancer survivors: a randomized controlled trial. *Psychoneuroendocrinology*, 43, 20-29.
doi:10.1016/j.psyneuen.2014.01.019
- Bowers, K. S. (1993). The Waterloo-Stanford Group C (WSGC) scale of hypnotic susceptibility: Normative and comparative data. *International Journal of Clinical and Experimental Hypnosis*, 41(1), 35-46. doi:10.1080/00207149308414536

- Bowers, K. S. (1998). Waterloo-stanford group scale of hypnotic susceptibility, form C: Manual and response booklet. *International Journal of Clinical and Experimental Hypnosis*, 46(3), 250-268. doi:10.1080/00207149808410006
- Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2013). A Guide for Analysing Electrodermal Activity (EDA) & Skin Conductance Responses (SCRs) for Psychological Experiments. Retrieved from <http://www.biopac.com/manuals/EDA%20SCR%20Analysis.pdf>
- Burr, R. L. (2007). Interpretation of normalized spectral heart rate variability indices in sleep research: a critical review. *Sleep*, 30(7), 913.
- Cardeña, E., Jönsson, P., Terhune, D. B., & Marcusson-Clavertz, D. (2013). The neurophenomenology of neutral hypnosis. *Cortex*, 49(2), 375-385. doi:10.1016/j.cortex.2012.04.001
- Charlot, K., Cornolo, J., Brugniaux, J., Richalet, J., & Pichon, A. (2009). Interchangeability between heart rate and photoplethysmography variabilities during sympathetic stimulations. *Physiological Measurement*, 30(12), 1357. doi:10.1088/0967-3334/30/12/005
- Christie, I. C., & Friedman, B. H. (2004). Autonomic specificity of discrete emotion and dimensions of affective space: a multivariate approach. *International Journal of Psychophysiology*, 51(2), 143-153. doi:10.1016/j.ijpsycho.2003.08.002
- Critchley, H. D., Mathias, C. J., Josephs, O., O'Doherty, J., Zanini, S., Dewar, B. K., . . . Dolan, R. J. (2003). Human cingulate cortex and autonomic control: converging neuroimaging and clinical evidence. *Brain*, 126(10), 2139-2152. doi:10.1093/brain/awg216

- Critchley, H. D., Melmed, R. N., Featherstone, E., Mathias, C. J., & Dolan, R. J. (2001). Brain activity during biofeedback relaxation: a functional neuroimaging investigation. *Brain*, 124, 1003-1012. doi:10.1093/brain/124.5.1003
- Crockett, A., & Panickar, A. (2011). Role of the sympathetic nervous system in pain. *Anaesthesia & Intensive Care Medicine*, 12(2), 50-54. doi:10.1016/j.mpaic.2010.10.023
- De Pascalis, V., & Perrone, M. (1996). EEG asymmetry and heart rate during experience of hypnotic analgesia in high and low hypnotizables. *International Journal of Psychophysiology*, 21(2), 163-175. doi:10.1016/0167-8760(95)00050-X
- Debeneditis, G., Cigada, M., Bianchi, A., Signorini, M. G., & Cerutti, S. (1994). Autonomic changes during hypnosis: a heart rate variability power spectrum analysis as a marker of sympatho-vagal balance. *International Journal of Clinical and Experimental Hypnosis*, 42(2), 140-152. doi:10.1080/00207149408409347
- Deeley, Q., Oakley, D. A., Toone, B., Giampietro, V., Brammer, M. J., Williams, S. C., & Halligan, P. W. (2012). Modulating the default mode network using hypnosis. *International Journal of Clinical and Experimental Hypnosis*, 60(2), 206-228. doi:10.1080/00207144.2012.648070
- Dekkers, J., Geenen, R., Godaert, G., Bijlsma, J., & Van Doornen, L. (2003). Elevated sympathetic nervous system activity in patients with recently diagnosed rheumatoid arthritis with active disease. *Clinical and experimental rheumatology*, 22(1), 63-70.
- Delmonte, M. (1985). Effects of expectancy on physiological responsivity in novice meditators. *Biological Psychology*, 21(2), 107-121. doi:10.1016/0301-0511(85)90009-2
- Demertzi, A., Soddu, A., Faymonville, M. E., Bahri, M., Gosseries, O., Vanhaudenhuyse, A., . . . Laureys, S. (2011). Hypnotic modulation of resting state fMRI default mode and extrinsic

- network connectivity. *Prog Brain Res*, 193, 309-322. doi:10.1016/B978-0-444-53839-0.00020-X
- Diamond, M. J. (1984). It takes two to tango: Some thoughts on the neglected importance of the hypnotist in an interactive hypnotherapeutic relationship. *American Journal of Clinical Hypnosis*, 27(1), 3-13. doi:10.1080/00029157.1984.10402582
- Diamond, S. G., Davis, O. C., & Howe, R. D. (2007). Heart-rate variability as a quantitative measure of hypnotic depth. *Intl. Journal of Clinical and Experimental Hypnosis*, 56(1), 1-18. doi:10.1080/00207140701672961
- Edmonston Jr, W. E. (1968). Hypnosis and electrodermal responses. *American Journal of Clinical Hypnosis*, 11(1), 16-25. doi:10.1080/00029157.1968.10401996
- Elkins, G., Barabasz, A. F., Council, J. R., & Spiegel, D. (2015). Advancing Research And Practice: The Revised APA Division 30 Definition Of Hypnosis. *Int J Clin Exp Hypn*, 63(1), 1-9. doi:10.1080/00207144.2014.961870.
- Elkins, G., Jensen, M. P., & Patterson, D. R. (2007). Hypnotherapy for the management of chronic pain. *Intl. Journal of Clinical and Experimental Hypnosis*, 55(3), 275-287. doi:10.1080/00207140701338621
- Elkins, G., Marcus, J., Stearns, V., Perfect, M., Rajab, M. H., Ruud, C., . . . Keith, T. (2008). Randomized trial of a hypnosis intervention for treatment of hot flashes among breast cancer survivors. *Journal of Clinical Oncology*, 26(31), 5022-5026. doi:10.1200/JCO.2008.16.6389.
- Fowles, D. C. (1986). The eccrine system and electrodermal activity. *Psychophysiology: Systems, processes, and applications*, 1, 51-96.

Fredrikson, M., Furmark, T., Olsson, M. T., Fischer, H., Andersson, J., & Långström, B. (1998).

Functional neuroanatomical correlates of electrodermal activity: a positron emission tomographic study. *Psychophysiology*, 35(2), 179-185. doi:10.1111/1469-8986.3520179

Gay, M.-C. (2007). Effectiveness of hypnosis in reducing mild essential hypertension: A one-year follow-up. *Intl. Journal of Clinical and Experimental Hypnosis*, 55(1), 67-83.

doi:10.1080/00207140600995893

Gemignani, A., Santarcangelo, E., Sebastiani, L., Marchese, C., Mammoliti, R., Simoni, A., &

Ghelarducci, B. (2000). Changes in autonomic and EEG patterns induced by hypnotic imagination of aversive stimuli in man. *Brain research bulletin*, 53(1), 105-111.

doi:10.1016/S0361-9230(00)00314-2

Gil, E., Orini, M., Bailón, R., Vergara, J., Mainardi, L., & Laguna, P. (2010).

Photoplethysmography pulse rate variability as a surrogate measurement of heart rate variability during non-stationary conditions. *Physiological Measurement*, 31(9), 1271.

doi:10.1088/0967-3334/31/9/015

Griffiths, M., Gillett, C., & Davies, P. (1989). Hypnotic suppression of conditioned electrodermal responses. *Perceptual and motor skills*, 69(1), 186-186. doi:10.2466/pms.1989.69.1.186

Grossman, P., Karemaker, J., & Wieling, W. (1991). Prediction of tonic parasympathetic cardiac control using respiratory sinus arrhythmia: the need for respiratory control.

Psychophysiology, 28(2), 201-216. doi:10.1111/j.1469-8986.1991.tb00412.x

Gruzelier, J., Allison, J., & Conway, A. (1988). A psychophysiological differentiation between

hypnotic behaviour and simulation. *International Journal of Psychophysiology*, 6(4), 331-338. doi:10.1016/0167-8760(88)90021-9

- Gruzelier, J., Brow, T., Perry, A., Rhonder, J., & Thomas, M. (1984). Hypnotic susceptibility: a lateral predisposition and altered cerebral asymmetry under hypnosis. *International Journal of Psychophysiology*, 2(2), 131-139. doi:10.1016/0167-8760(84)90006-0
- Gruzelier, J., & Brow, T. D. (1985). Psychophysiological evidence for a state theory of hypnosis and susceptibility. *Journal of Psychosomatic Research*, 29(3), 287-302. doi:10.1016/0022-3999(85)90056-X
- Harris, R. M., Porges, S. W., Clemenson, M. E., & Vincenz, L. M. (1993). Hypnotic susceptibility, mood state, and cardiovascular reactivity. *American Journal of Clinical Hypnosis*, 36(1), 15-25. doi:10.1080/00029157.1993.10403035
- Hippel, C. v., Hole, G., & Kaschka, W. (2001). Autonomic profile under hypnosis as assessed by heart rate variability and spectral analysis. *Pharmacopsychiatry*, 34(3), 111-113. doi:10.1055/s-2001-14279
- Horton-hausknecht, J. R., Mitzdorf, U., & Melchart, D. (2000). The effect of hypnosis therapy on the symptoms and disease activity in rheumatoid arthritis. *Psychology & health*, 14(6), 1089-1104. doi:10.1080/08870440008407369
- Jamieson, G. A., & Burgess, A. P. (2014). Hypnotic induction is followed by state-like changes in the organization of EEG functional connectivity in the theta and beta frequency bands in high-hypnotically susceptible individuals. *Frontiers in human neuroscience*, 8, 528. doi:10.3389/fnhum.2014.00528
- Jorgensen, M. M., & Zachariae, R. (2002). Autonomic reactivity to cognitive and emotional stress of low, medium, and high hypnotizable healthy subjects: Testing predictions from the high risk model of threat perception. *International Journal of Clinical and Experimental Hypnosis*, 50(3), 248-275. doi:10.1080/00207140208410102

- Kaufmann, T., Sütterlin, S., Schulz, S. M., & Vögele, C. (2011). ARTiiFACT: a tool for heart rate artifact processing and heart rate variability analysis. *Behavior research methods*, 43(4), 1161-1170. doi:10.3758/s13428-011-0107-7
- Kekecs, Z., & Varga, K. (2013). Positive suggestion techniques in somatic medicine: A review of the empirical studies. *Interventional Medicine and Applied Science*, 5(3), 101-111. doi:10.1556/IMAS.5.2013.3.2
- Kihlstrom, J. F. (1997). Convergence in understanding hypnosis? Perhaps, but perhaps not quite so fast. *International Journal of Clinical and Experimental Hypnosis*, 45(3), 324-332. doi:10.1080/00207149708416133
- Kihlstrom, J. F. (2013). Neuro-hypnotism: Prospects for hypnosis and neuroscience. *Cortex*, 49(2), 365-374. doi:10.1016/j.cortex.2012.05.016
- Kirsch, I. (2011). The altered state issue: Dead or alive? *International Journal of Clinical and Experimental Hypnosis*, 59(3), 350-362. doi:10.1080/00207144.2011.570681
- Kirsch, I., Milling, L. S., & Burgess, C. (1998). Experiential scoring for the Waterloo-Stanford Group C scale. *International Journal of Clinical and Experimental Hypnosis*, 46(3), 269-279. doi:10.1080/00207149808410007
- Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology*, 84(3), 394-421. doi:10.1016/j.biopsycho.2010.03.010
- Kreibig, S. D., Samson, A. C., & Gross, J. J. (2013). The psychophysiology of mixed emotional states. *Psychophysiology*, 50(8), 799-811. doi:10.1111/psyp.12064
- Kubota, Y., Sato, W., Toichi, M., Murai, T., Okada, T., Hayashi, A., & Sengoku, A. (2001). Frontal midline theta rhythm is correlated with cardiac autonomic activities during the

- performance of an attention demanding meditation procedure. *Cognitive Brain Research*, 11(2), 281-287. doi:10.1016/S0926-6410(00)00086-0
- Kunzmann, U., & Grühn, D. (2005). Age differences in emotional reactivity: the sample case of sadness. *Psychology and Aging*, 20(1), 47. doi:10.1037/0882-7974.20.1.47
- Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2014). Package 'lmerTest' version 2.0-11. Retrieved from <http://cran.r-project.org/web/packages/lmerTest>
- Lidberg, L., & Wallin, B. G. (1981). Sympathetic skin nerve discharges in relation to amplitude of skin resistance responses. *Psychophysiology*, 18(3), 268-270. doi:10.1111/j.1469-8986.1981.tb03033.x
- Lifshitz, M., Cusumano, E. P., & Raz, A. (2014). Meditation and hypnosis at the intersection between phenomenology and cognitive science *Meditation–Neuroscientific Approaches and Philosophical Implications* (pp. 211-226): Springer.
- Lipov, E., Lipov, S., Joshi, J., Santucci, V., Slavin, K., & Beck Vigue, S. (2007). Stellate ganglion block may relieve hot flashes by interrupting the sympathetic nervous system. *Medical hypotheses*, 69(4), 758-763. doi:10.1016/j.mehy.2007.01.082
- Lu, G., Yang, F., Taylor, J., & Stein, J. (2009). A comparison of photoplethysmography and ECG recording to analyse heart rate variability in healthy subjects. *Journal of medical engineering & technology*, 33(8), 634-641. doi:10.3109/03091900903150998.
- Lu, W.-A., & Kuo, C.-D. (2003). The effect of Tai Chi Chuan on the autonomic nervous modulation in older persons. *Medicine and science in sports and exercise*, 35(12), 1972-1976. doi:10.1249/01.MSS.0000099242.10669.F7
- Lynn, S. J., Fassler, O., & Knox, J. (2005). Hypnosis and the altered state debate: something more or nothing more? *Contemporary Hypnosis*, 22(1), 39-45. doi:10.1002/ch.21

- Malik, M., Bigger, J. T., Camm, A. J., Kleiger, R. E., Malliani, A., Moss, A. J., & Schwartz, P. J. (1996). Heart rate variability standards of measurement, physiological interpretation, and clinical use. *European heart journal*, 17(3), 354-381.
doi:10.1093/oxfordjournals.eurheartj.a014868
- Marsh, P., Beauchaine, T. P., & Williams, B. (2008). Dissociation of sad facial expressions and autonomic nervous system responding in boys with disruptive behavior disorders. *Psychophysiology*, 45(1), 100-110. doi:10.1111/j.1469-8986.2007.00603.x
- Maruzsa, S., Köteles, F., & Szekely, A. (2015). *Validation of an open-source bio-monitor for measuring electrodermal activity. Accepted for poster presentation.* Paper presented at the 19th Conference of the European Society for Cognitive Psychology (ESCOP), Paphos, Cyprus.
- Mazzoni, G., Venneri, A., McGeown, W. J., & Kirsch, I. (2013). Neuroimaging resolution of the altered state hypothesis. *Cortex*, 49(2), 400-410. doi:10.1016/j.cortex.2012.08.005
- McGeown, W. J., Mazzoni, G., Venneri, A., & Kirsch, I. (2009). Hypnotic induction decreases anterior default mode activity. *Consciousness and Cognition*, 18(4), 848-855.
doi:10.1016/j.concog.2009.09.001
- Merrifield, C., & Danckert, J. (2014). Characterizing the psychophysiological signature of boredom. *Experimental brain research*, 232(2), 481-491. doi:10.1007/s00221-013-3755-2
- Motivala, S. J., Sollers, J., Thayer, J., & Irwin, M. R. (2006). Tai Chi Chih acutely decreases sympathetic nervous system activity in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61(11), 1177-1180.
doi:10.1093/gerona/61.11.1177

- Oakley, D. A., & Halligan, P. W. (2013). Hypnotic suggestion: opportunities for cognitive neuroscience. *Nature Reviews Neuroscience*, 14(8), 565-576. doi:10.1038/nrn3538
- Palomba, D., Sarlo, M., Angrilli, A., Mini, A., & Stegagno, L. (2000). Cardiac responses associated with affective processing of unpleasant film stimuli. *International Journal of Psychophysiology*, 36(1), 45-57. doi:10.1016/S0167-8760(99)00099-9
- Parati, G., & Esler, M. (2012). The human sympathetic nervous system: its relevance in hypertension and heart failure. *European heart journal*, ehs041. doi:10.1093/eurheartj/ehs041
- Pattyn, N., Neyt, X., Henderickx, D., & Soetens, E. (2008). Psychophysiological investigation of vigilance decrement: boredom or cognitive fatigue? *Physiology & behavior*, 93(1), 369-378. doi:10.1016/j.physbeh.2007.09.016
- Peroutka, S. J. (2004). Migraine: a chronic sympathetic nervous system disorder. *Headache: The Journal of Head and Face Pain*, 44(1), 53-64. doi:10.1111/j.1526-4610.2004.04011.x
- Pinnell, C. M., & Covino, N. A. (2000). Empirical findings on the use of hypnosis in medicine: A critical review. *International Journal of Clinical and Experimental Hypnosis*, 48(2), 170-194. doi:10.1080/00207140008410047
- Randall, D. C., Brown, D. R., Raisch, R. M., Yingling, J. D., & Randall, W. C. (1991). SA nodal parasympathectomy delineates autonomic control of heart rate power spectrum. *Am. J. Physiol*, 260(3 Pt 2), H985-H988. doi:10.1080/00207140008410047
- Ray, W. J., Sabsevitz, D., Pascalis, V. D., Quigley, K., Aikins, D., & Tubbs, M. (2000). Cardiovascular reactivity during hypnosis and hypnotic susceptibility: Three studies of heart rate variability. *International Journal of Clinical and Experimental Hypnosis*, 48(1), 22-31. doi:10.1080/00207140008410358

- Sabourin, M. E., Cutcomb, S. D., Crawford, H. J., & Pribram, K. (1990). EEG correlates of hypnotic susceptibility and hypnotic trance: spectral analysis and coherence. *International Journal of Psychophysiology*, 10(2), 125-142. doi:10.1016/0167-8760(90)90027-B
- Sakakibara, M., Takeuchi, S., & Hayano, J. (1994). Effect of relaxation training on cardiac parasympathetic tone. *Psychophysiology*, 31(3), 223-228. doi:10.1111/j.1469-8986.1994.tb02210.x
- Santarcangelo, E. L., Paoletti, G., Balocchi, R., Carli, G., Morizzo, C., Palombo, C., & Varanini, M. (2012). Hypnotizability modulates the cardiovascular correlates of subjective relaxation. *International Journal of Clinical and Experimental Hypnosis*, 60(4), 383-396. doi:10.1080/00207144.2012.700609
- Schäfer, A., & Vagedes, J. (2013). How accurate is pulse rate variability as an estimate of heart rate variability? A review on studies comparing photoplethysmographic technology with an electrocardiogram. *International journal of cardiology*, 166(1), 15-29. doi:10.1016/j.ijcard.2012.03.119
- Selvaraj, N., Jaryal, A., Santhosh, J., Deepak, K. K., & Anand, S. (2008). Assessment of heart rate variability derived from finger-tip photoplethysmography as compared to electrocardiography. *Journal of medical engineering & technology*, 32(6), 479-484. doi:10.1080/03091900701781317.
- Takahashi, T., Murata, T., Hamada, T., Omori, M., Kosaka, H., Kikuchi, M., . . . Wada, Y. (2005). Changes in EEG and autonomic nervous activity during meditation and their association with personality traits. *International Journal of Psychophysiology*, 55(2), 199-207. doi:10.1016/j.ijpsycho.2004.07.004

- Terhune, D. B., Cardeña, E., & Lindgren, M. (2011). Differential frontal-parietal phase synchrony during hypnosis as a function of hypnotic suggestibility. *Psychophysiology*, 48(10), 1444-1447. doi:10.1111/j.1469-8986.2011.01211.x
- Tranel, D., & Damasio, H. (1994). Neuroanatomical correlates of electrodermal skin conductance responses. *Psychophysiology*, 31(5), 427-438. doi:10.1111/j.1469-8986.1994.tb01046.x
- van der Kruijs, S. J., Bodde, N. M., Carrette, E., Lazeron, R. H., Vonck, K. E., Boon, P. A., . . . Hofman, P. A. (2014). Neurophysiological correlates of dissociative symptoms. *Journal of Neurology, Neurosurgery & Psychiatry*, 85(2), 174-179. doi:10.1136/jnnp-2012-302905
- VandeVusse, L., Hanson, L., Berner, M. A., & White Winters, J. M. (2010). Impact of Self-Hypnosis in Women on Select Physiologic and Psychological Parameters. *Journal of Obstetric, Gynecologic, & Neonatal Nursing*, 39(2), 159-168. doi:10.1111/j.1552-6909.2010.01103.x.
- Vanhaudenhuyse, A., Laureys, S., & Faymonville, M.-E. (2014). Neurophysiology of hypnosis. *Neurophysiologie Clinique/Clinical Neurophysiology*, 44(4), 343-353. doi:10.1016/j.neucli.2013.09.006
- Venables, P., & Mitchell, D. (1996). The effects of age, sex and time of testing on skin conductance activity. *Biological Psychology*, 43(2), 87-101. doi:10.1016/0301-0511(96)05183-6
- Walton, K. G., Pugh, N. D., Gelderloos, P., & Macrae, P. (1995). Stress reduction and preventing hypertension: preliminary support for a psychoneuroendocrine mechanism. *The Journal of Alternative and Complementary Medicine*, 1(3), 263-283. doi:10.1089/acm.1995.1.263

Weitzenhoffer, A. M. (1989). The Induction of Hypnosis. In A. M. Weitzenhoffer (Ed.), *The practice of hypnotism* (2nd ed., pp. 135-220). New York, NY, US: John Wiley & Sons.

Woody, E. Z. (1997). Have the hypnotic susceptibility scales outlived their usefulness?

International Journal of Clinical and Experimental Hypnosis, 45(3), 226-238.

doi:10.1080/00207149708416125

Yüksel, R., Ozcan, O., & Dane, S. (2013). The effects of hypnosis on heart rate variability.

International Journal of Clinical and Experimental Hypnosis, 61(2), 162-171.

doi:10.1080/00207144.2013.753826