# Electrodermal activity as a valuable index of emotional arousal


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# Introduction

The focus of this dissertation is the **investigation of emotional arousal using bilateral, multi-site electrodermal activity (EDA) measurements**. In their handbook Dawson and his colleagues refer to EDA as "the most widely used – some might add "abused" – response systems in the history of psychophysiology" (Dawson, Schell, & Filion, 2007). My PhD work underlies this statement a hundred percent with several methodological points related to measurement details. We collected electrodermal data from 368 participants in 5 studies. Half of the experiments were carried out in group settings, which is relatively scarce in the EDA literature. Thus, this work carries valuable methodological insights to electrodermal data collection (e.g. time synchrony management).

**Electrodermal activity** has been around since the 1800s and has enjoyed tremendous attention in psychophysiology, also known as skin conductance or galvanic skin response, as measurement is based on activity of the eccrine sweat glands. Ease of measurement and practicality are two major reasons that made EDA a favored tool in research. Compared to other methods that gauge autonomic nervous system activity (such as heart rate variability or pupil dilation) EDA reflects the activity of the sympathetic and not the parasympathetic branch of this system.

Although affective processes are handled in many areas of the cortex, the limbic system plays a substantial contribution in processing emotions. Negative emotions are processed by the right hemisphere while positive emotions are processed predominantly by the left hemisphere. Consequently, **an arousal measurement that is sensitive to lateral differences could be quite useful in portraying a multi-dimensional picture of emotional processes**.

Most of EDA research is based on unilateral measurements taken from the non-dominant hand (most of the time the fingers). The unilateral measurement approach assumes that arousal is the same

across the body at any given time and that "**one true arousal**" can be measured from the non-dominant hand. This idea has not been challenged until very recently. The **Multiple Arousal Theory** (Picard et al., 2015) that on the other hand predicts that EDA could vary on different dermatomes, depending on several underlying generators of EDA (e.g. situational factors and the person's actual psychological state). This novel approach calls for multi-site measurements, which could not be accomplished easily with traditional measurement systems. Additionally, studies in the past usually were single subject experiments (since group measurements further complicate requirements set against the EDA measurement system). Yet, application of group experiments not only allow more swift data collection, but they also open the door to investigating psychological phenomena in a group setting which is practically missing from the literature.

**Measurement systems to be used in a group setting** require mobility and flexibility, features that do not fit those systems researchers used a few decades back. Psychophysiological measurement systems to date have gone through great advancements. Currently, wireless measurement systems are available, which allow unobtrusive and simple use, ready to apply in a group setting. Recent developments in technology also allowed researchers to step out of the laboratory and tap into "real life" data collection. They've also paved the way for advanced ambulatory measurements. In many studies the hands or the feet of participants may be busy doing some kind of task, therefore **alternate measurement places** were important to be identified to enable EDA data collection. These advancements require measurement sites that are inconspicuous, comfortable for long term wear, and do not interfere with everyday activities. These sites could not be the traditional hand or foot locations. Thus, exploration of alternate measurement sites has been warranted in this field.

**Traditionally** it is preferred to measure EDA from the fingers, because they have the highest density of eccrine sweat gland. Thus, measurements have been taken most often from the medial or the proximal phalanges of the index and middle fingers of the non-dominant hand which are the recommended places to measure from (Dawson, Schell, & Filion, 2007).

On the other hand, the **Multiple Arousal Theory** explains dermatome differences regarding EDA in an innovative way (Picard et al., 2015). According to the theory different emotional states are related to different cortical and subcortical brain regions. These brain regions act as neurological generators corresponding to unique pathways responsible for EDA. Thus, it is quite probable that multiple arousals are activated in the brain and body and it is indeed possible that some of these activations are consistently associated with unique experiences. Authors highlight that studies aiming to systematically link arousal patterns measured at different body parts to specific experiences are promising future lines of research related to the Multiple Arousal Theory. Studies of the present dissertation are good examples, extending and testing predictions of this novel theory.

Results show that sleep storms can be captured on the wrists but not on the fingers (Sano, Picard, & Stickgold, 2014). These results imply that there is some central activity in an **altered state of consciousness** in which the fingers are not the most sensitive dermatomes. This in turn may suggest that alternate electrodermal measurement places in an altered state of consciousness, are more sensitive to central changes as compared to traditional measurement sites, such as the palms of the fingers. Hypnosis is a state in which emotional processes take precedence over the sequential, and logical processing of the normal waking state. Furthermore, hypnosis induction is hypothesized to produce hemispheric changes that are different for high and low hypnotizable individuals. Major part of the dissertation

utilized bilateral EDA measurements to test if hypnosis induction produces different levels of arousal on the two sides of the body compared to a control condition and whether it is different for low and high hypnotizables.

## Objectives

The goal of this dissertation was to thoroughly examine the merit of multi-site measurements of electrodermal activity as a valuable index of emotional arousal in the framework of recent theories of electrodermal activity, with a special focus on the Multiple Arousal Theory, proposed by Rosalind W Picard in 2015.

Main objectives included

- validating new technology capable of group measurements and finding alternate electrodermal measurement locations for research and ambulatory purposes
- contrasting the traditional view of EDA with Multiple Arousal Theory by investigating dermatome differences induced by hypnosis and emotional stimuli.
- testing predictions of this theory regarding phasic electrodermal activity and to extend its predictions to different dermatomes than the palmar surfaces.
- widening the scope of the Multiple Arousal Theory by demonstrating applicability of the theory for explaining specific experiences typical in altered states of consciousness.

Five empirical studies were conducted to fulfill the above objectives (including 9 experiments, N = 368), validating, exploring and testing methodological and theoretical aspects of electrodermal activity changes in real time, linked to emotional arousal, evoked by various stimuli (e.g. emotionally laden musical segments and hypnotic induction).

**<u>Study 1.</u> reports validation of a new open source EDA device (Obimon) capable of group measurements**[1].

There is a simple, yet very specific feature of Obimon devices, namely that there are absolutely no wires. Electrodes transmit transfer skin conductance directly to the small device, which can be placed on multiple dermatomes (see them placed on feet and palms on the picture above). This feature makes them feasible for group measurements, with the possibility of multi-site application on each participant, which was essential to results I present in this thesis. Further important methodological issues, such automated and fluent time synchronization, seamless management of several devices, and real-time visualization of EDA via android phone/tablet application from many participants was demonstrated through validation studies against a reference system (Nexus).

Three experiments with 109 participants tested validity of the system using Pearson correlation, Passing-Bablok regression, and Bland-Altman analysis. During this diligent device validation, we used a broad spectrum of stimuli, characteristic in psychological experiments. New methodological aspects of this study include:

- This is the first attempt in the literature to systematically and rigorously validate an EDA measurement system using human subjects and a wide range of psychologically significant stimuli.
- It is the first study to publish group measurement data showcasing a wireless system capable of time synchrony, which could open up a new era of large-scale data collection, an aspect which is essentially missing from the EDA literature.

[1] Kasos, K., Zimonyi, S., Gonye, B., Köteles, F., Kasos, E., Kotyuk, E., Varga K., Veres A., Szekely, A. (2019). Obimon: An open-source device enabling group measurement of electrodermal activity. Psychophysiology, (2018), 1–15. https://doi.org/10.1111/psyp.13374

**<u>Study 2.</u> Moving away from the "One True EDA" traditions with respect to measurement locations, we compared simultaneous EDA activity changes in real time from 10 measurement sites[2].**

Novelty of this study is the exploration of alternate measurement sites bilaterally and comparing these EDA patterns to the traditional non-dominant finger location, providing essential information how SCL, SCR and SCR latency relates to the non-dominant fingers' location. In the first experiment (N=115), we measured EDA from 5 locations bilaterally (fingers, feet, wrists, calves and shoulders) during a breathing exercise and during presentation of an auditory stimuli. In the second experiment (N=20) we measured EDA during a 3-minutes-long musical stimulus and during the presentation of computer-generated tones.

**<u>Study 3.</u> expanded predictions of Multiple Arousal Theory from tonic to phasic electrodermal activity and to dermatomes of the lower body[3].** We explored if short emotional musical stimuli trigger different magnitude EDA responses on four different body locations: both fingers and both feet (N=38). Lateral and dermatome differences in phasic responses were investigated using group data collection. Novelties of this study include:

- The phasic component of EDA had never been tested based on the assumptions of the Multiple Arousal Theory.
- Musically induced emotions had never been investigated regarding bilateral EDA.
- The lower and upper body had never been compared based on the assumptions of the Multiple Arousal Theory.

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[2] Kasos K, Kekecs, Z., Csirmaz, L., Zimonyi, Sz., Vikor F, Kasos, E., Veres, A., Szekely A. (Under publication) Bilateral comparison of traditional and alternate electrodermal measurement sites. Psychophysiology. Accepted manuscript.

[3] Kasos, K., Zimonyi, S., Kasos, E., Lifshitz, A., Varga, K., & Szekely, A. (2018). Does the Electrodermal System " Take Sides " When It Comes to Emotions? Applied Psychophysiology and Biofeedback. https://doi.org/10.1007/s10484-018-9398-0

**Studies 4 and 5 contribute to our knowledge regarding how hypnosis affects electrodermal activity in both active alert[4] and traditional[5] hypnosis.** These studies bring attention to how bilateral electrodermal measurements may differentiate between psychophysiological patterns characterizing an altered state of consciousness as compared to normal waking state. In pursue of widening scope of the Multiple Arousal Theory, we tested the hypothesis that individual differences in bilateral EDA measurements may systematically characterize individuals with different levels of hypnotizability. We also hypothesized that laterality patterns, measured in real-time vary with consciousness.

**In study 4** (N=32) we measured from the shoulders bilaterally in a within subject design with two conditions: *active alert hypnotic induction* and during a music control condition.

**In study 5** (N=58) we investigated psychophysiological markers of the altered state of consciousness using *traditional relaxational hypnosis.*, taking bilateral measurements on a different dermatome: the wrists.

Novelty of these studies include:

- Measuring bilateral electrodermal activity in active alert hypnosis.
- Connecting subjective hypnotic experience to bilateral electrodermal changes.

I was curious if laterality differences between different hypnotizables are present during different types of hypnotic induction and if these differences could be captured on different dermatomes.

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[4] Kasos, K., Kekecs, Z., Kasos, E., Szekely, A., & Varga, K. (2018). Bilateral Electrodermal Activity in the Active–Alert Hypnotic Induction. International Journal of Clinical and Experimental Hypnosis, 66(3), 282–297. https://doi.org/10.1080/00207144.2018.1460551

[5] Kasos K, Csirmaz L, Vikor F, Zimonyi S, Varga K, Szekely A. Electrodermal Correlates of Hypnosis: Current Developments. OBM Integrative and Complementary Medicine 2020;5(2):20 http://www.lidsen.com/journals/icm/icm-05-02-017

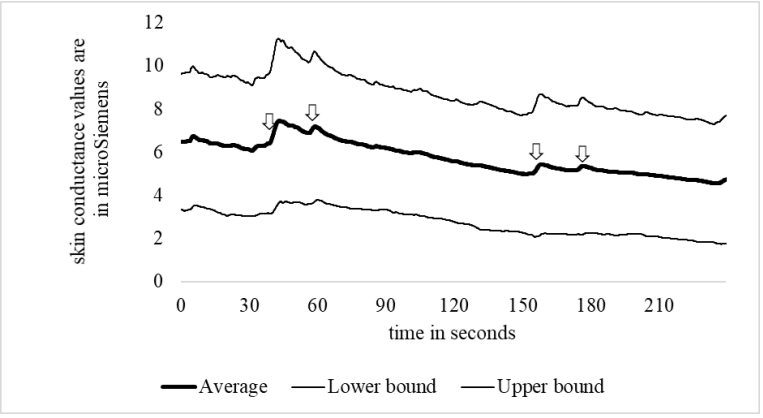
## Results

### Study 1: validating a new EDA measurement system

We demonstrated that measurements taken with the Obimon EDA system have high correlation with EDA measurements carried out with the reference system (Nexus). The average within-subject correlation of skin conductance levels measured by the tested and reference devices during the breathing exercise in experiment 1 was high: $r = .92$ and significant ($p < .001$). Similar between-subject correlations were reported in experiment 2, when amplitude of skin conductance responses were analyzed to psychologically significant stimuli: a scene from a short movie, where hands slap down on a chessboard ($r = .93$). According to results of the Passing-Bablok regression, EDA values measured by the two devices was not significantly different. The Bland Altman analysis also confirmed that the EDA measured by Obimon and Nexus is without significant bias.

- ***Obimon EDA measures are in agreement with a research grade device used frequently in psychophysiological studies.***

As a methodological advancement, Obimon opens new perspectives regarding real-time group measurement of electrodermal activity. Our results from experiment 3 demonstrated that many participants (limited only by the devices at hand) can be measured simultaneously, with a high degree of temporal precision. The figure below demonstrates average skin conductance level based on 76 participant's real-time EDA data during the repeated "now please breathe-in" instruction of the relaxation exercise at 38, 54, 151, 172 seconds represented by four arrows. Lines for lower and upper bound depict ± one standard deviation.




- ***Group measurement is a feasible option to collect EDA data.***

**Study 2: measuring bilateral EDA on alternate dermatomes**

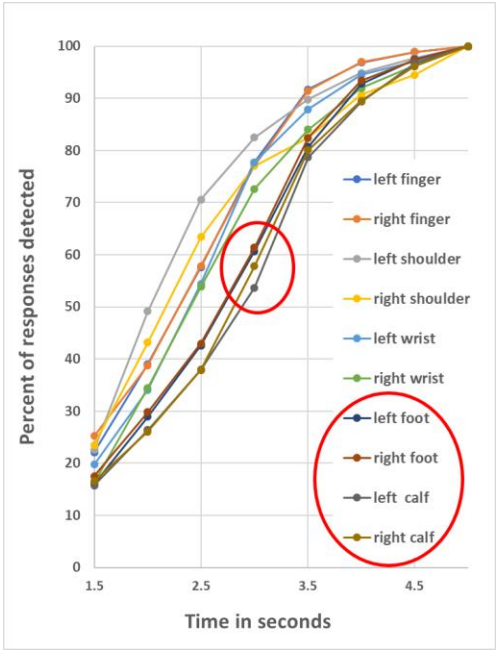
We found high response rates (to both to breathing instructions and to psychologically significant stimuli) from the fingers (96%) and the feet (90%). Response rates were lower from the wrists (57%). Lowest rates were found on the shoulders (29%) and the calves (52%).

- ***The traditional palmar and plantar measurement sites are the most responsive sites, followed by the wrists.***

High within-subject correlations were found between the electrodermal activity (EDA) measured from fingers bilaterally ($r$ = 0.89), between the left fingers and both feet ($r$ = 0.72). Moderate correlations were found between EDA measured from the left fingers and both wrists ($r$ = 0.30 and $r$ = 0.33). Correlations were not significant or very low (< 0.15) between the left fingers and alternate sites: shoulders and calves.

- ***The "One True EDA" as measured on the non-dominant finger is highly correlated with EDA from traditional measurement sites but not with wrists, shoulders and calves.***

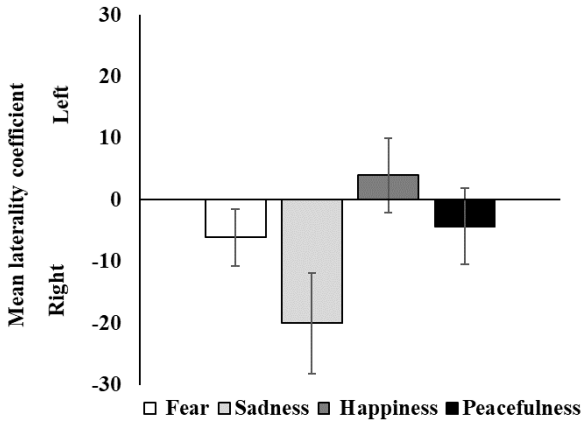
Short response windows (1-3 seconds) are promoted typically by researchers to avoid contamination of the response window with non-specific responses (e.g. Levinson et al., 1985; Steiner & Barry, 2011). Our results depicted by the figure on the right confirm that most responses detected on the fingers start within this short window. Most responses on shoulders and wrists were detected within this time frame. However, this short temporal window would most probably fail to capture some of the responses on the feet or the calves – see percent of responses on these dermatomes at the third second highlighted in the red circle.




- ***We suggest setting site-specific response windows for different EDA measurement locations.***

## Study 3: EDA responses to emotional musical stimuli underly the Multiple Arousal Theory

Our results show differences in electrodermal response laterality among musical segments conveying different emotions. We measured from the fingers and the feet. The laterality coefficient was used as a dependent variable in a one-way ANOVA yielding a significant effect of the type of emotion the stimuli conveyed $F(1, 38) = 4.88$, $p = .01$, $\eta 2 = .11$ on palmar surfaces. The figure below depicts mean laterality coefficient of stimuli types representing different emotions. The Y axis represents laterality; values < 0 show right side dominance, values > 0 show left side dominance. Error bars represent ± 1 standard error of the mean.




Palmar EDA responses to musical segments of *happiness* was lateralized the most to the *left*. Peacefulness and fear were lateralized more to the right. *Sadness* elicited the most "*right-sided*" palmar EDA responses. Post hoc analyses of each pair of lateral EDAs to these emotions revealed only one significant result; sadness is more right sided than happiness $t(38) = –2.83$, $p = .007$ (level of significance was Bonferroni-corrected for the six analyses). Similar analyses using the plantar measurement sites (both feet) did not reveal the same pattern of responses, no significant differences were found between pairs of these emotions.

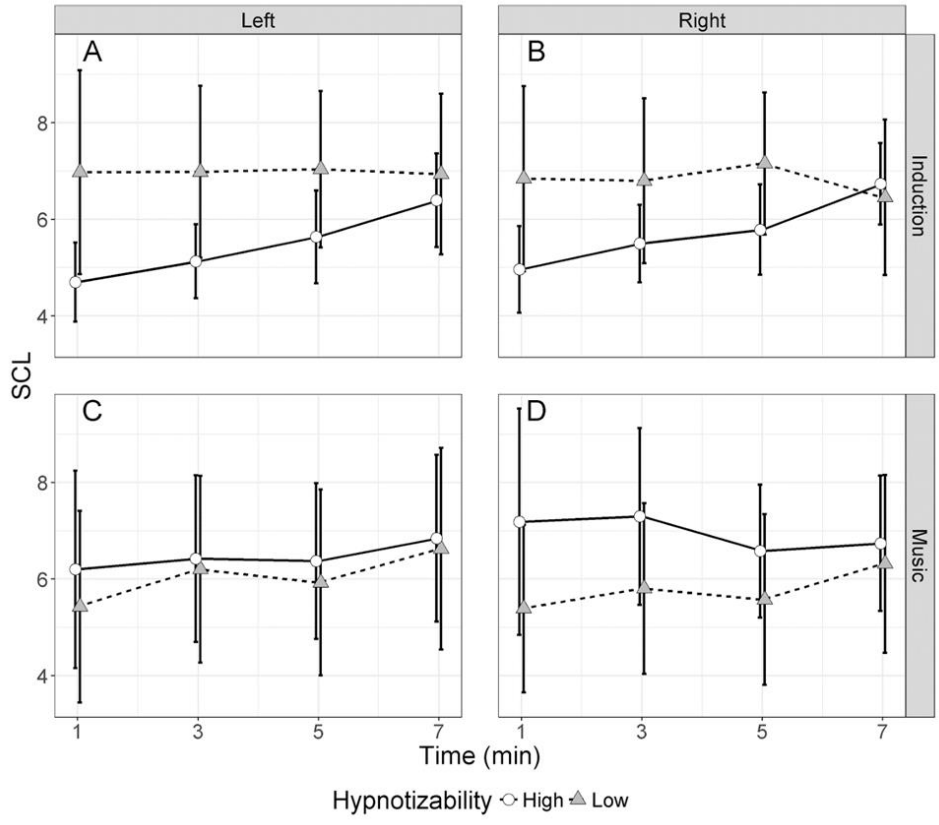
Self-reported state anxiety scores showed a negative correlation with laterality of EDA responses to musical stimuli conveying fear $r = − .410$ ($p = .027$).

- ***Musical stimuli laden with different emotions elicits different electrodermal responses across dermatomes and sides. Palmar EDA for sadness is more right sided as compared to happiness. Individual differences in state anxiety correspond to the extent of right sidedness to fearful music.***

**Study 4: hypnotizability and real-time bilateral EDA, measured on the shoulders during active alert hypnosis**

Based on prior experiences and assumptions of the Multiple Arousal Theory, we assumed that bilateral EDA level and patterns will be characteristically different for low and high hypnotizables. These differences are assumed to be present in the altered state of consciousness of hypnosis, but not necessarily during a control condition with musical stimuli.

The figure below depicts left and right sided EDA patterns of highs and lows in the two conditions. Level of skin conductance for high and low hypnotizables show a reversed pattern in the two conditions. Highs can be characterized by a lower EDA level than lows in the hypnosis, but not in the control condition. Their EDA levels rise gradually during hypnosis, but not in the control conditions. Further analyses of bilateral EDA patterns confirm that laterality patterns vary with both hypnotizability and condition.



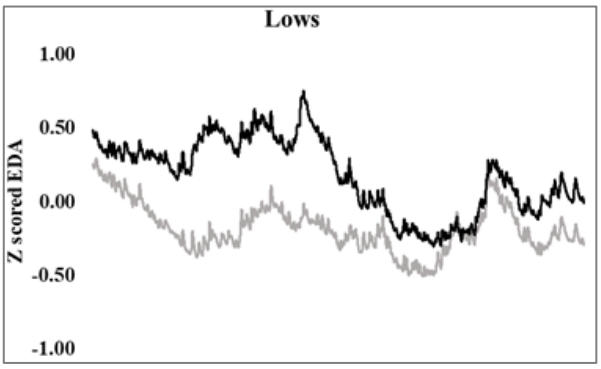

- **EDA patterns are specific to hypnotizability and condition.**

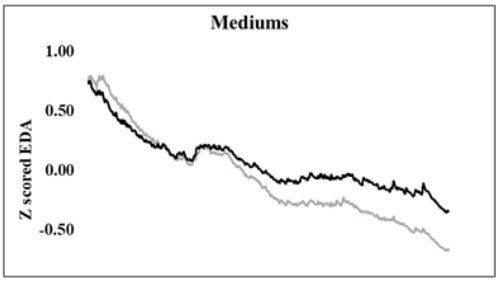
## Study 5. Lateral differences on wrist EDA during the induction phase of traditional hypnosis.

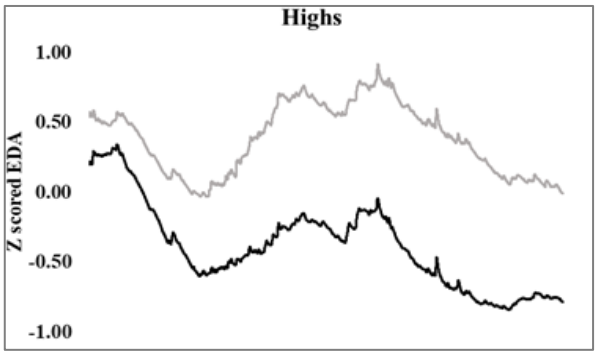
In the hypnosis induction phase, a standard set of preliminary instructions and suggestions are communicated to the individuals being hypnotized. The way people reach or fail to reach the hypnotic state is of vital importance. Based on previous hypnosis literature a reduction in SCL during the hypnotic induction was hypothesized, especially in those who score high on the hypnotizability scale.

Bilateral EDA was measured from the wrists of high, medium and low hypnotizables during the induction phase of traditional hypnosis. We aimed to reduce individual variability in electrodermal levels to detect lateral changes with time, a characteristic of the three hypnotizability groups. Thus, data were standardized within individuals, using the average level of skin conductance values and the standard deviations of all data points from both wrists.

Using the Z-scored EDA for every data point a three-way mixed ANOVA was performed during the 10-minute induction phase using side (left/right) and time as within-subject factors and hypnotizability as a between-subject factor. The figures on the right depict changes in Z-scored EDA during induction, averaged for the left and for the right hands of the three hypnotizability groups. A prominent effect of time with $F(4,140) = 2.65$, $p = 0.036$, $\eta p2 = 0.07$ revealed a gradual decrease on both sides during induction in all three groups. There were no other main effects.



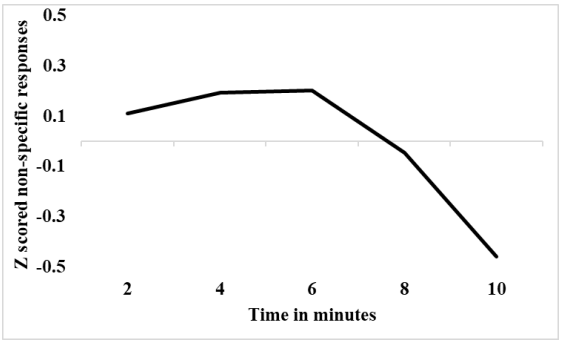



A significant three-way interaction of side, time and hypnotizability was observed $F(8,140) = 2.49$, $p = .015$, $\eta p^2 = .13$. Low, medium and high hypnotizables showed characteristically different EDA patterns on their left and right sides. While lows showed right side dominance, highs showed left side dominance throughout the induction phase. The levels of left and right-side skin conductance were very close in medium hypnotizables.

- ***Level of skin conductance shows a gradual decrease on both sides regardless of hypnotizability; however, bilateral EDA patterns are characteristically different: lows show right side dominance whereas highs showed left side dominance throughout the induction phase.***

In line with the above results of a gradual decrease in EDA levels and based on results of prior research, we predicted that fewer SCRs will characterize the end of the induction phase compared to the beginning of the induction. Findings from the literature also suggests less non-specific SCRs in EDA patterns of high hypnotizables as compared to lows. Three-way mixed ANOVA analysis was performed on the number of z-scored SCRs during every two minutes of the induction phase. We used time and side as within subject factors, and hypnotizability (low/medium/high) as a between subject factor. Results conformed the main effect of time $F(4,116) = 2.839$, $p = .027$, $\eta p^2 = .09$. The number of SCRs were reduced significantly during the induction, regardless of side or hypnotizability. The figure on the right shows Z-scored non-specific responses during every 2-minutes of the induction phase, averaged for the two sides of EDA measurement.




- ***The number of non-specific responses is lower on both sides at the end of induction compared to the beginning of the induction for all hypnotizability groups.***

## Discussion

The goal of this dissertation was to thoroughly examine the merit of multi-site measurements of electrodermal activity as a valuable index of emotional arousal in the framework of recent theories of electrodermal activity, with a special focus on the Multiple Arousal Theory, proposed by Rosalind W Picard in 2015. Five empirical studies were conducted (including 9 experiments, N = 368) to validate, explore and test methodological and theoretical aspects of the electrodermal activity changes in real time, linked to emotional arousal, evoked by various stimuli (e.g. laden musical stimuli or hypnotic induction).

The electrodermal system's complex nature has been overlooked up until recently. Current understanding of the way this system behaves under different circumstances is limited by the One Ture Arousal Model of electrodermal activity. Results from Studies 1-5 outlined in this dissertation confirm, that arousal is not uniform across dermatomes. Confirming and extending the Multiple Arousal Theory, we attested both level of skin conductance and responses to emotional stimuli. Results presented in this thesis underline dermatome differences in both of these EDA measures, moreover, the lower and upper body seems to show different patterns of responses to the same emotional stimulus. Our findings clearly support the notion suggested by Picard and colleagues in the framework of the Multiple Arousal Theory, that electrodermal activity levels on different dermatomes converge or diverge bilaterally, depending on the situation and psychological predisposition of the individual.

In studies of the present dissertation on altered state of consciousness, alternate measurement sites proved to be very useful in differentiating people with different hypnotizability, both in active alert and traditional hypnosis. During the hypnotic induction, the left and right side diverged in a markedly different (reversed) pattern in low and high hypnotizables. Based on these findings multisite measurements

are necessary to further understand the nature of this complex system. Exploration of alternate measurement sites and dermatomes could reveal interesting insights to understanding individual differences in response to diverse stimuli in different psychological states.

The One True Arousal model entrenched the idea of the one channel recording of EDA. This dissertation questions this practice, providing results and methodological insights to promote a shift towards considering an alternative approach to emotional arousal. We call for multi-site measurements in both laboratory and ambulatory recordings. In an ideal situation all dermatomes should be mapped and recorded. To accomplish this, we need recording systems that are small, wireless and comfortable to wear. Until such time this idea takes hold, we should at least take bilateral measurements.

I propose that in the near future EDA recording methods could take the form of a multichannel recording setup, similar to the common practice of EEG recordings used today. Results presented in this thesis call the attention to the need of a paradigm shift in electrodermal research. The traditional view of uniform arousal measured by EDA ought to be re-evaluated, and a new paradigm based on the Multiple Arousal Theory should be considered.

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