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Does the Electrodermal System "Take Sides" When It Comes to Emotions?

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Abstract

Traditionally, electrodermal research measurements were taken from the non-dominant hand. This was considered a valid measurement of arousal for the whole body. Some, however argue for a complex and asynchronous electrodermal system in terms of lateral and dermatome differences in emotional responding. The present study measured skin conductance responses to emotionally laden musical stimuli from the left and right index and middle fingers, as well as the left and right plantar surface of right handed participants (N = 39). The 7-s musical segments conveyed four emotional categories: fear, sadness, happiness and peacefulness. Our results suggest, that the electrodermal system responds to emotional musical stimuli in a lateralized manner on the palmar surfaces. Fear, sadness and peacefulness prompted right hand dominance while happiness elicited left hand dominant response. Lateralization of the palmar and plantar surfaces differed significantly. Moreover, an association between lateralization of the electrodermal system in response to fear and state anxiety was found. Results of the present study suggest that the electrodermal system displays lateral preferences, reacting with varying degree of intensity to different emotions. Apart from lateral differences, music induced emotions show dermatome differences as well. These findings fit well with Multiple Arousal Theory, and prompt for revaluating the notion of uniform electrodermal arousal.

Keywords Electrodermal · Emotion · Music · Laterality · Arousal

Introduction

In electrodermal research it is important to understand whether different emotional stimuli favor either side of the body, if they manifest with the same proportionate intensity in all parts of the body, and how our anxiety effects lateral preferences. There are indications, that the sympathetic nervous system (SNS) has no problem "taking sides" when it comes to emotions, leading to a lateralized electrodermal response to emotion evoking stimuli (Banks et al. 2012).

According to Boucsein et al. (2012) electrodermal activity (EDA) is related to the activity of the sympathetic branch of the autonomic nervous system (ANS). One way to record EDA is to measure skin conductance. Skin conductance can be divided into phasic and tonic components, both being informative measures of the SNS. The phasic component of skin conductance response (SCR) measures quick transient changes and it is mostly used to study cognitive processes along with emotional responses. The other component is skin conductance level (SCL) which describes the background activity of the SNS, mainly used as a measure of general arousal (Dawson et al. 2007).

Studies regarding EDA asymmetry yielded conflicting results to date. Early electrodermal research reported lateral differences between the two hands (Baitsch 1954; Fisher and Abercrombie 1958; Fisher and Cleveland 1959; Obrist 1963). Others on the other hand found no such asymmetry (Hugdahl et al. 1982; Gross and Stern 1980; O'Gorman and Siddle 1981) or found that asymmetry was not influenced by the type of stimuli presented (Erwin et al. 1980; Maltzman and Boyd 1984). For a detailed review of early reports on the subject see Freixa i Baqué et al. (1984). Nonetheless,

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in electrodermal research skin conductance responses were typically measured only from the non-dominant hand, and these values were considered as valid measurements of arousal for the whole body (Hempel et al. 2005; Lane et al. 1997; Petrovic et al. 2008; Kekecs et al. 2016). Recent literature (intended as a guide for analyzing EDA) overlooks the issue of laterality, promoting unilateral recordings (Braithwaite et al. 2013).

Recently Banks et al. (2012) pursued the potential for a lateralized response to emotions. Their study employed six types of stimuli. Five basic emotions using emotionally expressive faces (fear, sadness, happiness, anger, disgust), and a neutral stimulus. Their results showed larger electrodermal response amplitude on the right side to anger, disgust and fear. Sadness, happiness and neutral stimuli, on the other hand, showed greater amplitude on the left side. These results are important because they show the lateral nature of the sympathetic nervous system (SNS) regarding five basic emotions in a social context. The study used a wide response window after stimuli onset (9 s), which is unorthodox in electrodermal research, and it makes results difficult to compare to other studies in the field.

Based on recent findings there may be more to differential electrodermal responding than only the lateralization of the autonomic nervous system. The most recent theory explaining the multi-dimensional nature of arousal, its neurological underpinnings and its manifestation in electrodermal activity is the Multiple Arousal Theory of EDA (Picard et al. 2015). According to this theory different levels of arousal could be present at the same time in different parts of the body in response to emotional stimuli. These differences are caused by different neurological generators corresponding to unique pathways responsible for EDA. The ipsilateral or contralateral influences of these pathways have been debated, yielding conflicting results. There is indication for contralateral influence during tasks that the investigators considered left or right hemispheric (Myslobodsky and Rattok 1977). In contrast ipsilateral influences were also assumed by Sourek (1965). Some explain their results in terms of contralateral inhibition (Lacroix and Comper 1979; Boyd and Maltzman 1983). However, the same results could be interpreted in terms of unilateral excitation (Freixa i Baqué 1984; Miossec et al. 1985). There are indications that motor influences are contralateral and excitatory (Gruzelier et al. 1988). Mangina and Beuzeron-Mangina (1996) found that direct stimulation of the four cortical areas examined in their study exert symmetrical bilateral influences on EDA while stimulation of the 8 limbic structures that were studied have an ipsilateral influence. Overall, results show that some of these pathways have contralateral influences on EDA (for example motor influences), some of them, such as the frontal cortical convexities exert bilateral, while others such as limbic structures, exert ipsilateral influences (Picard et al. 2015). The Multiple Arousal Theory also suggests that some dermatomes are more prone to show higher skin conductance than others when exposed to emotions. The most studied manifestation of this feature is laterality differences in EDA. Granted, if EDA is measured from the palmar surfaces, Multiple Arousal Theory predicts that, emotions more likely processed by the right hemisphere (such as fear and sadness) would elicit lateralized responses favoring the right hand. Emotions that are more likely processed by the left amygdala (e.g. anger) would generate greater responses on the left hand. However, the same lateral differences might not hold on the legs, or on other dermatomes of the body.

One way to convey and elicit emotions is by utilizing music (Juslin and Laukka 2004; Wells and Hakanen 1991; Sloboda 1992; Gabrielsson 1993). With its inherent dynamics and temporal characteristics, it is well suited for modelling emotion, eliciting real life responses which develop dynamically in time.

In their initial study Peretz et al. (1998) showed that participants were able to differentiate between two emotions (sad and happy) conveyed by musical stimuli in a time interval, as short as 0.25 s. In their later research using music conveying fear, sadness, peacefulness and happiness, participants were able to confidently differentiate between these emotions under 4 s (Vieillard et al. 2008). In electrodermal research musical segments eliciting emotions have only been used in a single unilateral study (Khalfa et al. 2002). These segments were 7 s long. They used three basic emotions (fear, sadness and happiness), and one complex emotion (peacefulness). Peacefulness was chosen as the opposite of fear. Researchers concluded that electrodermal responses to happiness and fear were significantly larger than responses to sadness and peacefulness. In the present study we investigated the effects of similar 7 s long musical segments measuring responses bilaterally from the palmar and plantar surfaces.

Results from previous electrodermal measurements suggests that anxiety relates to arousal. Based on unilateral EDA research, elevated level and variability of EDA is typical in those, with higher state anxiety: e.g. increased number of nonspecific responses and retardation of habituation were reported (Katkin 1965; Maltzman et al. 1971). Association between trait anxiety and SCL, as well as SCR amplitude and longer latencies was also reported (Naveteur et al. 1987). Bilateral long-term EDA measurements suggest that state anxiety evoking situations, especially those that involve some kind of personal threat, push the electrodermal system towards right side dominance (Picard et al. 2015). Bishop and colleagues (2004, 2007) using FMRI investigated, how anxiety affects response of the amygdala to emotional faces. They found that those who scored higher on state anxiety showed more activation of the amygdala in response to fearful faces as compared to those with low state anxiety.

These results suggest that state anxiety of participants have a moderating effect on the amygdala's activation. In electrodermal research little attention has been payed so far to the moderating effects of state anxiety on bilateral responding to emotional stimuli.

The purpose of this study is to assess how emotions (elicited by music excerpts conveying different emotions) lateralize the electrodermal system. Based on previous results (Banks et al. 2012; Picard et al. 2015) and the predictions of the Multiple Arousal Theory, we hypothesized that emotionally laden stimuli will produce lateralized EDA responses. If measured from the palmar surface, happiness will presumably favor the left side, while fear is expected to favor the right side. This is in line with results of Lanteaume et al. (2007) who found, that positive emotions are more likely processed by the left amygdala and negative emotions are more likely processed by the right amygdala. We also investigated sadness and peacefulness, emotions, which yielded contradicting results regarding laterality, earlier. We also assessed, if electrodermal laterality is different on the palmar and plantar surfaces.

In addition, we investigated the moderating effects of anxiety on the laterality of electrodermal responses to emotion, conveyed by musical segments. We hypothesize that higher anxiety will be associated with a more right-sided response to emotional stimuli.

Methods

Participants

The study protocol was approved by the ethical board of the Eötvös Loránd University. Thirty-nine right-handed participants' (mean age = 20.75, SD = 1.75) electrodermal responses to short 7 s long musical excerpts were analyzed in the study. Participants received course credit for attendance. Exclusion criteria for the study were: self-reported use of psychiatric drugs, use of sedatives, any psychiatric illness, auditory impairments. Out of the 39 valid cases 8 plantar surface measurements could not be used due to excessive sweating, 10 participants were lost due to missing questionnaire data.

Procedure

Informed consent form was filled out and detailed information concerning the procedure was provided. Participants were tested in small groups of 2–5, in a quiet lab at the Psychology Institute at Eötvös Loránd University. The room's temperature was between 21 and 24 °C. Participants were asked to sit facing the walls to make sure the facial expressions of the other participants were not visible. The electrodermal activity sensors were attached by the experimenter to the left and right intermediate phalanges of the index and middle fingers and the left and right plantar surfaces as described in van Dooren et al. (2012). At the start of the experiment, a guided breathing exercise was played in Hungarian which lasted 4 min. The purpose of the exercise was to provide participants with the opportunity to adapt to experimental conditions.

Four 7 s musical excerpts (see Vieillard et al. 2008) were played in a randomized order. The musical fragments used here and their classification to emotional categories was developed by Vieillard et al. in a study which aimed to provide suitable musical material for research on emotions (2008). The musical excerpts were meticulously validated for classification, and discrimination accuracy of arousal and valence.

Each stimulus presentation was followed by a 45 s break allowing the skin conductance level to return back to baseline. During the breaks between segments, participants were asked to rate the musical segments regarding the type of emotion (fear, sadness, happiness, peacefulness). They were also asked to rate the segments, on a Likert scale ranging between 1 and 10, regarding their clarity, whether they were calming or stimulating (self-reported level of arousal), and their valence. Once finished, participants were debriefed, thanked for their participation and the devices were removed.

Equipment and Data Processing

The State Trait Anxiety Inventory (STAI) is a self-report questionnaire consisting of two subscales: one for state and one for trait anxiety (Spielberger et al. 1970). Both subscales consist of 20 questions. We used the state anxiety subscale, measuring how participants felt at the moment. The scores can range between 20 and 80, higher scores representing grater anxiety. It has been suggested that scores over 40 points may signal clinically significant anxiety (Addolorato et al. 1999; Julian 2011).

For the measurement of skin conductance, the Open-Source Bio monitor (Obimon) was used with an 8-Hz sampling rate (Kasos et al. submitted). Skin conductance was recorded with 2 (32 × 41 mm) disposable pairs of Ag/AgC1 electrodes (Skintact FS-RG1; Leonhard Lang GmbH. Innsbruck, Austria). Electrodermal activity was analyzed with Ledalab 3.4.9 (Benedek and Kaernbach 2010). In order to decrease error noise, the data was first smoothed with a Gaussian window. Skin conductance response (SCR) was obtained by optimized continuous decomposition analyses (Benedek and Kaernbach 2010). The 4-s window for analyzing electrodermal response was set 1 s after stimuli onset. Only SCRs larger than 0.05 µS were analyzed.

EDA laterality coefficients were calculated with the formula below (Papousek and Schulter 2006; Schulter and

Papousek 1992, 1998), where negative values represent right side advantage and positive values represent left side advantage expressed in percentage. Thus, a result of 14 for example means that the left side response is 14% higher than the right-side response.

$$\textit{Laterality coefficient} = \frac{(\textit{left hand SCR amp.} - \textit{right hand SCR amp.})}{(\textit{left hand SCR amp.} + \textit{right hand SCR amp.})} \times 100$$

Results

Subjective Ratings of the Musical Excerpts

Participants rated how clearly the emotion was conveyed by the musical segments on a scale ranging from 1 to 10. Friedman test was conducted with 36 valid responses to see if any of the emotions conveyed were rated different from the others with the following results $\chi^2(3) = 42.12$, $p < .001$ (Fig. 1). Post hoc analyses of clarity ratings of each emotion were conducted using a Bonferroni corrected p value of .008. Wilcoxon signed rank tests show that fear and happiness were rated clearly higher on clarity than sadness and peacefulness.

Ratings of arousal and valence were also portrayed for the four stimuli types used (see Fig. 2). The Friedman test (conducted with 36 valid responses) for valence ratings yielded significant differences of the four emotions: $\chi^2(3) = 39.81$, $p < .001$. Pair by pair Wilcoxon signed ranks tests showed that the stimulus conveying fear was rated more unpleasant than happiness $Z = -4.45$, $p < .001$; sadness $Z = -4.36$, $p < .001$ and peacefulness $Z = -4.56$, $p < .001$ (p values are significant after the stringent Bonferroni correction for multiple testing: $.05/6 = .008$).

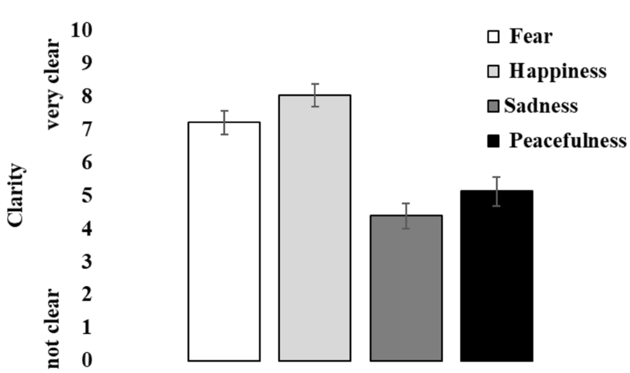

Fig. 1 Clarity ratings for all four types of stimuli. Higher values represent higher clarity. Error bars represent ± 1 standard error of the mean

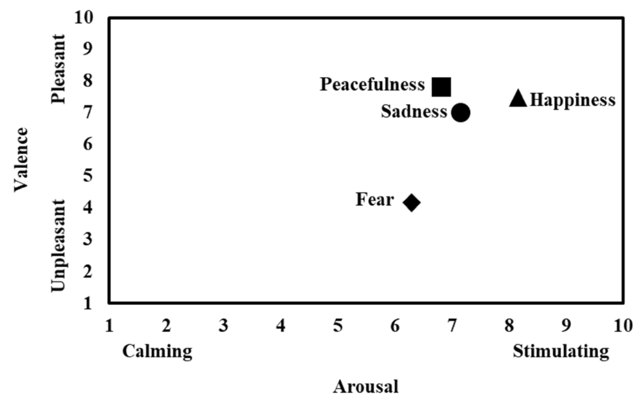

Fig. 2 Subjective ratings of arousal and valence on a 10-point scale, where lower values represent lower arousal and less pleasant stimuli while higher values represent higher arousal and more pleasant stimuli

The Friedman test ($N = 36$) on the subjective ratings of arousal also showed significant differences: $\chi^2(3) = 14.32$, $p = .002$. The Wilcoxon signed rank tests (using the Bonferroni adjusted p value of .008) showed, that participants rated the musical excerpts expressing happiness significantly more arousing than fear $Z = -2.78$, $p = .005$ and peacefulness $Z = -2.93$, $p = .003$.

Laterality Coefficient Results on the Palmar Surface

The electrodermal response of 36 subjects to different emotional stimuli was compared using a within subject design. Figure 3 represents mean laterality values of fear, sadness, happiness and peacefulness stimuli types.

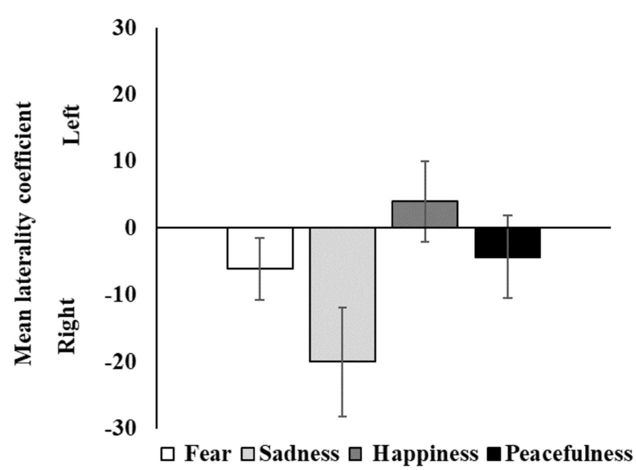

Fig. 3 Mean laterality coefficient of stimuli types representing different emotions (palmar surface). Error bars represent ± 1 standard error of the mean. The Y axis represent the percentage difference between the two sides. Numbers below zero represent right side dominance, while numbers above zero represent left side dominance

Zero laterality coefficient means that the two sides of the body respond in absolute synchrony. To test if any of the emotions lateralized the electrodermal system significantly we ran a one sample t-test with 0 as a test value representing absolute synchrony. According to the results of the one sample t-test only sadness lateralized the body significantly $t(38) = 2.54$, $p = .019$, Cohen's $d = .45$. Thus, participants responded to sad musical excerpts with a clear right dominance.

The laterality coefficient was used as a dependent variable in a one-way ANOVA yielding a significant effect of emotion type of the stimuli used $F(1, 38) = 4.88$, $p = .01$, $\eta^2 = .11$. Responses to stimuli conveying happiness was most lateralized to the left, on the other hand peacefulness, sadness and fear was lateralized to the right, and sadness appeared to be the most "right-sided". To see which emotion was significantly different from one-another, a post hoc analysis was conducted. The paired sample t tests comparing lateralization of all stimuli pairs revealed only one significant difference between sad and happy stimuli $t(38) = -2.83$, $p = .007$ (level of significance was Bonferroni-corrected for the six analyses).

State Anxiety and Laterality

Mean value of state anxiety scores: 37.66 (SD = 7.54) in our sample is in line with the published scores: 36 (SD = 10) for this age group (Spielberger et al. 1970). Association of individual scores of self-reported state anxiety and the laterality coefficient of individual EDA responses for each stimuli type (described above) was investigated using the Spearman correlation coefficient. Results showed a significant negative correlation between laterality of responses to fear and state anxiety $r = -.410$, $p = .027$ (see Fig. 4). Higher anxiety scores were associated with more right lateralization towards fearful stimuli. There were no other significant correlations.

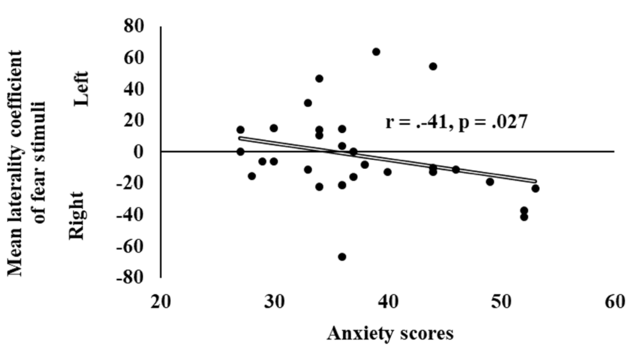

Fig. 4 Relationship between anxiety and lateralization towards fearful stimuli. The Y axis represent the percentage difference between the two sides. Mean laterality coefficient numbers below zero represent right side dominance, while numbers above zero represent left side dominance

Results Regarding the Plantar Surface

Figure 5 represents lateralization on the plantar surfaces regarding the four types of emotional musical stimuli used. First, we compared, whether any of the induced emotions are lateralized enough on the plantar surface to differ significantly from absolute synchrony (represented by 0 laterality coefficient). One sample t-tests resulted in a non-significant trend for the fear response $t(30) = 1.71$, $p = .098$. No other significant results were found.

Laterality of electrodermal responses to different emotional musical stimuli was also compared using a within subject design, using the laterality coefficient as the dependent variable in a one-way ANOVA. The results yielded no significant differences in lateralization of the four stimuli types, as measured on the plantar surfaces (Fig. 5).

The association between anxiety and the laterality coefficient was also investigated, and no significant results were found using the Spearman correlation coefficient.

Results Comparing the Palmar and Plantar Surfaces

To compare the palmar and plantar surfaces regarding responses to emotional stimuli we used a two-way, mixed-design ANOVA, with the within subject factor of emotion (fear, sadness, happiness and peacefulness) and the between subject factor of body parts (palmar and plantar). No significant main effects were found. Results yielded a marginally significant interaction effect of emotion and body parts F(3,

Fig. 5 Mean laterality coefficient of stimuli types representing different emotions (plantar surface). Error bars represent ± 1 standard error of the mean. The Y axis represent the percentage difference between the two sides. Numbers below zero represent right side dominance, while numbers above zero represent left side dominance

28) = 2.70, p = .05, effect size = .08. Responses to emotional stimuli seem to show different pattern of lateralization when measured from the palmar as opposed to the plantar surfaces. Fear and sadness were lateralized more to the left on the plantar surfaces, while these two emotions showed a right lateralization on the palmar surfaces. Happiness and peacefulness on the other hand showed no lateral differences as measured on the two body parts.

Discussion

To our knowledge, this is the first study to compare electrodermal laterality differences regarding emotions elicited by music. We explored laterality differences between the two sides of the body, as well as between the upper and lower body. Also, association between participant' self-reported anxiety and electrodermal laterality were examined for the first time in the present study. Our results support predictions of Multiple Arousal Theory concerning laterality differences on the palmar surfaces (Picard et al. 2015). We found markedly different electrodermal reactions for fear and sadness on the palmar surfaces, on the other hand, no similar differences could be observed using EDA data from the plantar surfaces. We conclude that different type of emotions lateralize the electrodermal system in a unique way.

Apart from the objective electrodermal laterality measures, participants also provided subjective ratings of clarity, as well as arousal and valence of the four types of musical segments. The present study shows different patterns of subjective ratings of arousal and valence, as compared to those reported in other studies for similar musical excerpts (Khalfa et al. 2002; Vieillard et al. 2008). The most striking difference is related to the arousal ratings of peacefulness and sadness. In this paper we presented arousal ratings amongst which only happiness differed from fear and peacefulness. This might be due to cultural differences: based on a recent review, different cultures favor emotions that are rated either low or high on arousal (Lim 2016).

One would always expect some deviation from synchrony in regards to electrodermal activity between the two sides of the body, since the distribution of sweat glands are not exactly symmetrical (Freedman et al. 1994). According to our results only sadness tilted the balance significantly to the right side, as compared to absolute synchrony represented with 0 value on the laterality scale. When comparing laterality of the different emotions, we found sadness and happiness taking opposite sides: happiness lateralized to the left and sadness to the right when comparing the palms. These results confirm our hypothesis that emotionally laden musical stimuli elicit lateralized electrodermal responses.

Lateralization of happiness and fear confirm all previous findings (Banks et al. 2012; Picard et al. 2015). On the other hand findings on sadness were the opposite of the findings of Banks et al. (2012). The differences may be due to methodological reasons, or caused more likely by the different stimuli categories used in our studies (faces vs. music). Different types of stimuli aiming to elicit the same emotion category were found to bring about dissimilar central activation (Reiman et al. 1997). Reiman et al. (1997) in their study either exposed participants to visual stimuli or they were prompted to recall an emotionally laden memory. Different activation was found for the same type of emotion when triggered by recall or visual stimulation. Another study found that viewing sad faces was associated with the activation of the left amygdala, which in turn has an ipsilateral influence on EDA (Lane et al. 1997). It has been postulated before, that there could be more than one central pathway to the mediation of EDA (Kimble et al. 1965), and it was later confirmed by Boucsein et al. (2012) and Picard et al. (2015). A possible explanation based closely on Multiple Arousal Theory is that if different central pathways are activated with different type of emotion eliciting stimuli, the activated pathways could have various degree of influence on EDA. This could easily result laterality differences between visually and auditorily induced emotional responding.

The plantar surfaces did not show statistically significant laterality differences of the four studied emotional types, only a trend for left side dominance was found for the fear response deviating from absolute synchrony. Comparing EDA responses to emotional stimuli of the plantar with those of the palmar surfaces, we reported an interaction effect: laterality response to sadness on the feet did not shift significantly away from synchrony as opposed to the robust effect witnessed on the hands. On the other hand, responses to happiness and peacefulness inducing stimuli were similar on both body parts. Thus, there seems to be more to electrodermal responding than a simple lateral difference between the two sides of the body. Our findings underline that different dermatomes are prone to respond to certain type of emotional stimuli which is postulated by Multiple Arousal Theory. More specifically, the feet and the palms show a divergent pattern of responding to the same type of musical segment.

Electrodermal laterality and anxiety was investigated for the first time in our study. Participants' self-reported state anxiety was associated with their laterality responses to four types of emotional stimuli. Results showed that higher anxiety elicited more right sided fear responses on the palmar surfaces. This emotional laterality effect was specific to this emotion only, and to the palmar but not the plantar surfaces. These results support the laterality effects observed in the electrodermal responses to fearful stimuli. They are in line with the findings of Bishop and colleagues

(2004, 2007) who found that state anxiety moderated the activity of the amygdala's response to fearful stimuli.

Limitations

Limitations of this study include data lost from the plantar surfaces due to excessive sweating. Securing equipment on such surfaces is essential. The correlation between anxiety and the electrodermal lateralization of the emotion fear should be handled with care due to low sample size.

Conclusions

The complex nature of the electrodermal system in terms of differences in emotional mapping has not been fully appreciated. Results of the present study confirm that electrodermal responses are not uniform across the body. The autonomic nervous system displays lateral preferences by reacting with varying intensity to different emotions. Music induced emotions show not only lateral preferences but dermatome differences as well. These findings fit well with previous results (Banks et al. 2012; Picard et al. 2015) and prompt for revaluating the homogeneous concept of electrodermal arousal. With the use of bilateral EDA measurement from dermatomes across the body in electrodermal research, we could gain better understanding of how differentiated emotional responses are.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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