Measuring site dependency when measuring skin conductance

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Skin conductance is one of the most commonly used physiological parameters in psychophysiology today. Because of its simplicity, straightforwardness of usage, simple and low-cost measuring instruments and reasonable correlation with the activity of the autonomous nervous system, it has been used in various psychological studies. While there is no generally accepted measuring site for measuring skin conductance, it is usually measured on the distal phalanxes of the index and middle finger, which we consider as the reference measuring site. Nowadays, different measuring devices exist, which employ different measuring sites. In this paper the most commonly used measuring sites were compared with the reference site for a group of healthy volunteers in psychologically neutral (relaxed) state disturbed by a stimulus. Our results show the degree of comparability of various measuring site versus the reference site.

1 Introduction

Measuring electro dermal activity (EDA) is one of the most convenient methods for observing changes of sympathetic nervous system. Electrical properties of the skin vary in response to sweat secretion and provide information associated with emotion, cognition and attention [1, 2].

By applying a low constant voltage at skin surface, the change of skin conductance can be measured non-invasively [3]. Measurement consists of placing electrodes on a recording site on skin, which are then connected to sensitive galvanometer (Figure 1). Because of a correlation of skin conductance (i. e. the amount of secreted sweat) and the activity of the autonomous nervous system, by measuring change of electric potential one can observe changes caused by activity of sweat glands [4].

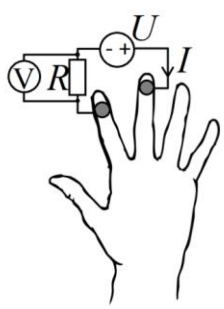

Figure 1. Basic principle of measuring skin conductance. Between electrodes (grey circles) low constant voltage *U* is applied, resulting in current *I* through skin. *I* is indirectly measured using a voltmeter and a shunt resistor R. Skin conductance can then be calculated from *U* and current *I*.

In published psychophysiological studies as the measuring sites usually distal phalanxes of middle and index finger, the palm, the wrist, but also other parts of body (forearm, feet) are chosen [1, 5]. All of these recording sites are distinctive by their responses due to number of sweat glands on the specific area. These distinctions consequently cause different responses in skin conductance induced by psychological, cognitive or physical efforts.

This paper presents comparison of skin conductance measurements at different sites of recording. Electrodes were attached to several different locations of our interest and while the observed person was in psychologically neutral state the differences in skin conductance of various body parts were estimated.

2 Methods

2.1 Participants

The measurements were performed on 8 healthy volunteers; 2 women and 6 men aged between 21 and 41. Prior to data collection, each participant was provided a clear description of what was required for participation and thereafter was asked to carefully read and sign the consent form. Participants were given the right to withdraw from the study at any stage.

2.2 Apparatus

Measurements were taken by MP150 high speed data-acquisition system combined with GSR100C and BN-PPGED-EDA amplifiers by Biopac Inc, USA. By using a test subject it was experimentally proven that there is no interaction between the amplifiers. Data was recorded at the proposed sample rate of 2000 Hz [7]. Two types of Ag/AgCl electrodes were used, both in combination with isotonic gel. PPGED was connected to disposable isotonic gel electrodes while GSR100C was connected to appropriate reusable electrodes (TS203). Isotonic gel used for measurements (GEL101) consisted of 0.5 % chloride salt in neutral base.

2.3 Stimuli

Although properties of electro dermal responses to specific stimuli are not in the centre of attention of this paper, some form of stimulus during the measurement was found to be necessary. Reason for this was a better comparison between two signals. Taking in consideration this assumption, there was no need for uniform stimuli during all measurements. Therefore, each participant was asked to create some response in the skin conductance level by means of activating autonomous nervous system by simple actions such as hyperventilation, taking deep breath, light slapping, laughing, scratching and coughing (Figure 2).

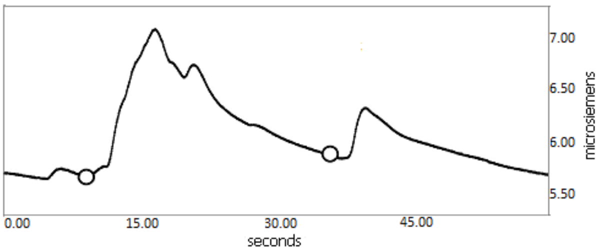

Figure 2. One minute of raw signal of the skin conductance of a person when coughing (indicated by white circles), which resulted in an instant increase of the signal level.

2.4 Procedure

For every participant measurements were taken on 6 different measuring sites; 5 sites on the right arm and 1 on the right foot (Figure 3). As the reference measuring site distal phalanx of index and middle finger pair of electrode placement was selected for all subjects [8]. Reference skin conductance was measured continuously using the Biopac GSR100C amplifier. Other recording sites were measured by Biopac BN-PPGED-EDA amplifier and included palm, wrist, pair thumb - little finger, back of the upper arm and inner side of the foot.

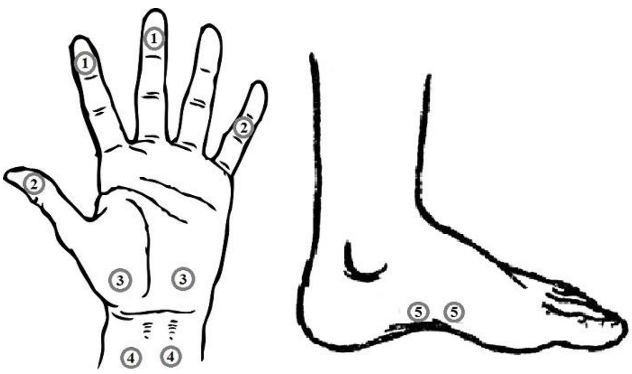

Figure 3. Placement of electrode pairs on different measuring sites: 1.) Distal phalanxes of index and middle finger, 2.) Distal phalanx of thumb and medial phalanx of little finger. 3.) Thenar and hipothenar eminence at the palm of hand, 4.) Wrist, 5.) Medial site on the inner side of the foot.
6.) Back of the upper arm (not shown in Figure)

After the electrodes were attached on participant's skin the participants were instructed to sit comfortably and place their hands on table. This helped avoiding possible moving artefacts due to unwanted/unintentional body movement. Participants were then instructed to relax for a 5 minute rest period allowing the conductive gel to be absorbed, making an optimal electrical contact. During the rest period measurement procedure was explained to participants. Skin conductance data was recorded in intervals of 1 minute for each recording site, in total 5 sites. Approx. 1 minute periods were allowed in between the intervals for physiological signals to return to baseline. The entire measurement protocol lasted approximately 20 minutes per participant.

3 Results

During the analysis pairs of signals were compared; the reference signal measured on distal phalanxes of index and middle finger and the signal from one of the other five recording sites. Our hypothesis is based on the assumption that if recorded conductance at reference and observed site correlate, we would be able to conclude whether a certain observed site could be considered appropriate for measuring skin conductance and comparable to the reference measuring site. For each pair of signals, correlation coefficient was calculated to quantify the correspondence of signals (Tables 1 to 6). In Table 7 approximate values of skin conductance that can be expected at each measuring site are presented.

Table 1. Correlation coefficients for skin conductance signal from electrodes placed on distal phalanx of thumb and medial phalanx of little finger

Participant	Correlation coefficient
1.	0.97818
2.	0.97102
3.	0.96255
4.	0.97416
5.	0.88263
6.	0.98574
7.	0.92842
8.	0.91412

Table 2. Correlation coefficients for skin conductance signal from electrodes placed on thenar and hipothenar eminences of the palm

Participant	Correlation coefficient
1.	0.86683
2.	0.96332
3.	0.95079
4.	0.90923
5.	0.85319
6.	0.97915
7.	0.95440
8.	0.94239

Table 3. Correlation coefficients for skin conductance signal from electrodes placed on wrist

Participant	Correlation coefficient
1.	0.57380
2.	0.68597
3.	0.37197
4.	-0.03959
5.	0.73115
6.	0.83055
7.	-0.16559
8.	0.50671

Table 4. Correlation coefficients for skin conductance signal from electrodes placed on medial site on inner side of the foot

Participant	Correlation coefficient
1.	0.98178
2.	0.95816
3.	0.56036
4.	0.77655
5.	0.83925
6.	0.82445
7.	0.85988
8.	0.91550

When observing signal from electrodes placed on the inner side of the foot, distinctive characteristic can be seen. For several participants there was a significant time delay between signals recorded at reference and observed site (Figure 4). This time delay ranged between 0.5 and 1 second for most participants, and once it was removed, i.e. signals were aligned, correlation coefficient was notably improved (Table 5).

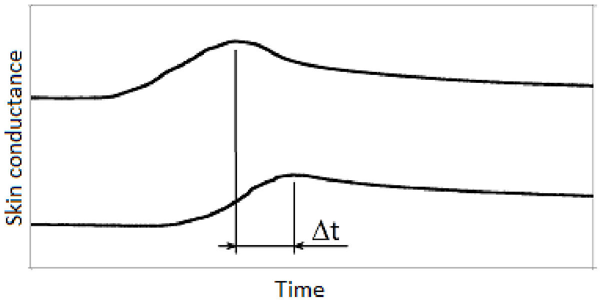

Figure 4. Segment of recorded raw skin conductance signal versus time showing the time delay Δ*t* between signal recorded on the inner side of foot (lower curve) and reference signal (upper curve). Values of time delays for each recording are shown in Table 5.

Table 5. Approximate time delay between observed (inner side of foot) and reference site and correlation coefficient after time correction

Participant	Time delay (s)	Correlation coefficient*
1.	0	0.98178
2.	0.5	0.96069
3.	3.5	0.88440
4.	1	0.85609
5.	0	0.83925
6.	0.9	0.86422
7.	0.95	0.91328
8.	0.7	0.96065

Table 6. Correlation coefficients for skin conductance signal from electrodes placed on the back side of the upper arm

Participant	Correlation coefficient
1.	0.26411
2.	-0.62442
3.	-0.06131
4.	0.01052
5.	-0.23813
6.	0.44881
7.	0.21131
8.	0.12730

Based on high correspondence of signals, measuring sites on palm (correlation factor between 0.85 and 0.98), on inner side of the foot (correlation factor between 0.85 and 0.99), and between thumb and little finger (correlation factor between 0.88 and 0.99) can be considered to be comparable to reference site when measuring skin conductance in psychophysiology. For signals on the palm and between thumb and little finger higher amplitudes as compared to those recorded between index and middle finger were expected. Table 7 shows that seven participants out of eight had higher amplitudes on observed than on the reference site.

From the results given in Tables 3 and 6, measuring sites located at wrist and at back side of the upper arm can be considered as inappropriate/insensitive for skin conductance measurements. This could be concluded because very few participants showed responsiveness on these sites. Simultaneously, it took a lot of effort to attach electrodes to this sites in such a way to be able to even obtain such recordings. Long periods of inactivity of these recording sites is described in literature [1]. Inappropriate for measuring skin conductance meaning, that we observe skin responses to gather data about psychophysiological state of participant. On the other hand, taking this in consideration, they might be possible to use these sites for measuring physical activity [6, 7].

Table 7. Range of absolute values of recorded signals (in micro Siemens)

Measuring site	Range of signal amplitudes	Mean value
index-middle finger	2.97↔8.89	5.44
thumb-little finger	5.09↔20.02	8.34
palm	1.93↔12.68	6.85
wrist	1.79↔12.65	5.41
inner side of foot	2.53↔14.4	5.32
back side of upper arm	0.49↔2.22	2.34

Table 8. Ratio of amplitude at the observed and amplitude at reference measuring site, both in steady-state condition (not during stimulus). Ration 1 means the observed site response equals the reference site and 1.53 that observed amplitudes were higher than reference ones. NA – the acquired signals were not usable.

Measuring site	Range of ratios (observed/reference)	Mean value
thumb-little finger	0.89↔2.35	1.53
palm	0.59↔2.35	1.58
wrist	NA	-
inner side of foot	0.35↔2.57	0.97
upper arm	NA	-

Absolute values in Table 7 are noted to roughly show expected values at each observed site as compared to the distal phalanxes of index and middle finger reference measuring site.

4 Conclusion

The paper is describing a case study of effect of measuring site when measuring skin conductance. 8 healthy volunteers were included into the study. A series of EDA electrodes were attached to 5 different measuring sites and their readings compared to the reference site - distal phalanxes of index and middle finger. The measuring protocol was composed of 5 minutes conditioning rest period, followed by five one minute intervals of task period. Task included a sudden change of skin conductance signal, induced by hyperventilation, scratching, slapping etc.

From the results we conclude that palmar, foot inner side and thumb-little finger measuring sites are suitable for recording electrodermal activity for purposes in psychophysiology and comparable to the reference measuring site. In general, for these sites the correlation coefficients between signals were close to 1.

Based on our results a study of habituation, gender influence (possible hyperresponsiveness for female) is planned in the future.

Literature

[1] W. Boucsein: Electrodermal activity, second ed., Springer, New York, 2012.

[2] D. C. Fowles, M. J. Christie, R. Edelberg, W. W. Grings, D. T. Lykken, P. H. Venables: Publication Recommendations for Electrodermal Measurements, Psychophysiology, vol. 18, no. 3, 1981.

[3] H. D. Critchley: Electrodermal Responses: What Happens in the Brain, Neuroscientist 2002 8: 132

[4] G. Geršak: Enostavni nizkocenovni merilniki prevodnosti kože, Elektrotehniški vestnik 80(1-2): 64-72, 2013.

[5] A. S. Scerbo, L. Weinstock Freedman, A. Raine, M. E. Dawson, P. H. Venables: Major Effect of Recording Site on Measurement of Electrodermal Activity, Psychophysiology, vol. 29, no. 2, 1992.

[6] M. Z. Poh, N. C. Swenson, R. W. Picard: A Wearable Sensor fo Unobtrusive, Lon-Term Assessment of Electrodermal Actovity, IEEE Trans. Biomed. Eng. vol. 57, no. 5, 2010.

[7] A. Teller: A platform for wearable physiological computing, Interacting with Computers, vol. 16, pp. 917–937, 2004.