A Comparison of Different Electrodermal Variables in Response to an Acute Social Stressor

Anne-Marie Brouwer[1(✉)], Maurice van Beurden[1], Lars Nijboer[2], Luc Derikx[2], Olaf Binsch[1], Christa Gjaltema[1], and Matthijs Noordzij[2,3]

[1] TNO Human Factors, Soesterberg, The Netherlands
anne-marie.brouwer@tno.nl
[2] Department of Cognitive Psychology and Ergonomics, Universtiy of Twente, Enschede, The Netherlands
[3] Department of Psychology, Health, and Technology, Universtiy of Twente, Enschede, The Netherlands

Abstract. We investigated electrodermal activity (EDA) in 130 participants undergoing a shortened version of a novel easy, effective and controlled method to induce stress (the Sing-a-Song Stress Test). We compared skin conductance level (SCL), amplitude and number of skin conductance response peaks with respect to their sensitivity to the known stressor, for different scenarios of interests. EDA increased after stressor-onset for almost all participants. At a group level, the three variables were about equally sensitive. When examining the increase following the stressor with respect to preceding EDA within one individual, peak amplitude was most sensitive. Peak measures were clearly most sensitive in a simulated between-subject scenario (i.e., testing the difference in EDA between stress and non-stress intervals as if data originated from different, stressed and non-stressed groups of individuals). Peaks can be extracted by continuous decomposition (CDA) or through-to-peak analysis (TTP). In all analyses performed, CDA outperformed TTP. We thus recommend CDA peak amplitude for monitoring physiological stress effects in e.g. symbiotic systems.

Keywords: Electrodermal activity · GSR · Skin conductance · Stress Arousal · Stress induction · Sing-a-Song Stress Test

1 Introduction

The ability to cope with high levels of emotional, cognitive and physiological stress is an important skill for many professionals, such as soldiers or police officers, since they operate in complex and highly demanding environments. The current developments in gaming and simulation technology and the miniaturization of sensor and monitoring technology offers an opportunity to develop new advanced training systems combining VR technology, serious gaming environments and physiological computing. There is increasing interest to use simulated environments to change the content based on the current individual stress experience. In symbiotic applications such as these, stress

© Springer International Publishing AG, part of Springer Nature 2018
J. Ham et al. (Eds.): Symbiotic 2017, LNCS 10727, pp. 7–17, 2018.
https://doi.org/10.1007/978-3-319-91593-7_2

should be estimated in individuals without needing to question them about their stress experience - individuals should not be distracted from the task they are performing. Another example where one is interested to monitor individuals continuously and study when a stress response occurs, and how strong this is, is monitoring phobic patients such that their treatment can be tailored [1]. A different type of scenario that benefits from implicit markers of stress are studies that evaluate the success of a stress resilience training (i.e., examining the stress response of a group of individuals that received training to that of a control group) or compare stress responses in other types of groups (e.g. pathological, or professional – [2]). This is especially important when dealing with populations who have difficulties to properly indicate their level of stress verbally, or are expected to show response bias when using questionnaires. In these examples, one would like to test the response to a known stressor between groups rather than responses within an individual. Finally, it may be of interest to know whether an individual is in a stressed state or not (e.g. a patient coming in for treatment). In this case, there is no individual baseline value or known stress response. In each case one might need a different set of evaluation criteria to predict the experienced stress of an individual.

Electrodermal activity (EDA), or changes in the electrical activity of the skin, has been recognized for decades to be a reliable marker of physiological arousal, which can be considered as an important component of stress. It is thought to reflect activity of the 'fight or flight' sympathetic branch of the autonomous nervous system [3, 4]. The physiological basis for EDA is not fully understood, but sweat gland activity is certainly implicated [5]. We here consider commonly used skin conductance variables that can be observed when applying an external source of current on the skin (i.e. exosomatic method), in contrast to only using skin potential (endosomatic method – [5]). Active sweat glands cause higher conductivity of current. To quantify this, different variables can be extracted from the raw signal: overall Skin Conductance Level (SCL) during a given period of time, and variables related to fast skin conductance changes (skin conductance responses, hereafter referred to as 'peaks'). Peak-related variables include the number of peaks and their mean amplitude during a given period in time. In order to detect these peaks, hand-extracted through-to-peak (TTP) methods have originally been used. These methods have later been automated by finding values exceeding certain thresholds [6]. Another approach (CDA-continuous decomposition analysis) that is less dependent on the individual shapes of the peaks was proposed by Benedek and Kaernbach [4]. Using deconvolution of the skin conductance signal, the tonic (SCL) and the phasic (skin conductance peak) activity can be recovered.

We here systematically compare the sensitivity of different electrodermal variables to a well-timed, acute social stressor that is controlled for body movements in a large number of participants. Many current methods that have been used to induce stress result in relatively modest physiological changes (e.g. [7, 8]) or are not controlled for body movements (which by themselves affect physiology) and are relatively cumbersome (e.g. [9]). In the current study, the presentation of the stressor follows a modified version of the 'Sing-a-Song Stress Test' (SSST) [10]. In the SSST, participants are presented with 9 'neutral' sentences, each followed by a countdown interval of 60 s. After that, a sentence is presented in which participants are asked to sing a song of their choice aloud after the end of the subsequent countdown interval during which

participants sit still in the same way as before. This procedure leads to relatively strong increases in heart rate, skin conductance level and pupil size when comparing the countdown interval following the stress sentence to the one following the last neutral sentence [2, 10]. In the current study, we further shortened the stress induction procedure by using less sentences and intervals of 30 rather than 60 s. Also, the neutral sentences involved mental tasks. The original version of the SSST cannot differentiate between effects of cognitive mental processes (associated with task difficulty, which has been shown to increase of electrodermal activity – [11]) and effects of affective processes. Using sentences that ask participants to perform cognitive tasks rather than have them only read a sentence is an attempt to somewhat rectify the difference in cognitive load between the stress sentence (leading participants to think of a song they would want to sing) and the neutral sentences. Finally, the current version of the SSST features one rather than two individuals as audience for the singing. Taken together, this new, shortened version, requiring less people, can be finished under ten minutes. This makes it a very fast and low demand social stress alternative for the well-known and effective, but more cumbersome Trier Social Stress Test [9].

The sensitivity of electrodermal variables to a stressor can be defined for a whole group (where a high sensitivity indicates that all recorded individuals show a large increase of electrodermal activity in response to the stressor) or for an individual (where a high sensitivity indicates that the increase of electrodermal activity in response to the stressor is high compared to the variability in electrodermal activity of that individual in the preceding time interval). In addition, we can view effects of a stressor as a state, i.e. without making use of the electrodermal baseline of the individual. In that case, a sensitive electrodermal variable as recorded after a stressor displays high values relative to the mean and the variation of measurements in a baseline situation. These three types of sensitivity map onto the three groups of examples mentioned at the start of the introduction. The stress response in a group is important for comparing different groups; the stress response within an individual relative to a longer preceding interval is important for adaptive automation such as adapting gaming content to an individual's state; the stress state without knowing a personal baseline is important for applications in which the question is whether newly observed individuals are in a state of more or less stress. We compare the sensitivity of SCL, peak amplitude and number of peaks (where the latter two variables are extracted using CDA or (automatic) TTP) under each of these three scenarios.

2 Methods

2.1 Participants

154 participants (mostly college students participating for course credit) took part in the experiment. As recommended [6], visual checks were performed on plots of skin conductance data to identify failed measurements, "non-responding" individuals (indicated by an absence of peaks in a given measurement) or incorrect classification of peaks. Data from these problematic measurements as well as data in which other technical problems occurred during measurement were removed from further analysis.

After this quality control step data from 130 participants remained. Mean age was 22 years (std = 3.4, range = 18–42) and 85 were female. Participants were told that the experiment was about personality and fitness and were debriefed about the real purpose afterwards. The study was approved by the ethics committee of the University of Twente. All participants signed an informed consent in accordance with the Declaration of Helsinki, stressing the right to quit participation at any time.

2.2 Materials

Electrodermal activity was measured with two skin conductance sensors from the Biograph infiniti package (Bio-Medical instruments, Clinton Township, MI, USA). The skin conductance sensors were placed on the ventral side of the medial phalanges of the ring and index finger at the left hand and kept in place with Velcro straps. Recording frequency was 256 Hz and sensor supply voltage was 7.3 mV.

2.3 Design and Procedure

After signing the informed consent form, the participant was seated behind a laptop to fill out two questionnaires with demographical and personality questions (not analyzed here). After the participant finished the questionnaires, the experimenter invited a confederate in the room as a second participant whose turn it would be next. The confederate was seated behind the laptop (supposedly to fill out the questionnaires as well) while the participant was relocated in the same room to sit approximately 60 cm in front of a 1280 × 720 60 Hz flat screen with the experimental stimuli. Sensors to measure skin conductance and heart rate (not analyzed here) were attached. Participants were asked to move as little as possible and follow the instructions on the screen that were exchanged with a counter counting down until the next instruction. (See for the exact instructions Table 1). Participants were first instructed to sit calm and relax

Table 1. Instructions translated into English and the duration of the subsequent countdown interval.

	Instruction	Duration (s)
Baseline 1/4	Sit calm, try to relax and focus on your breathing while watching the counter counting down	120
Neutral 1	Think of animals starting with the letter P	30
Neutral 2	Think of objects one can find in a kitchen	30
Neutral 3	Think of the necessary items when organizing a wedding	30
Neutral 4	Think of as many team sports practiced without a ball as possible	30
Preparing	The next assignment will be to sing a song aloud – think about songs to sing for the next 30 s	30
Singing	Now sing a song for 30 s aloud and try to keep your arms still. Keep singing!	30
Baseline 5/8	Sit calm, try to relax and focus on your breathing while watching the counter counting down	120

for 2 min. Then four times an instruction to perform a simple cognitive task was displayed for 5 s, each time followed by a countdown interval in which a number on the screen counted from 30 to 1. Then the sing-a-song stress sentence was presented, telling the participants that they would be instructed to sing after the countdown interval had ended. In the subsequent singing instruction, participants were asked to sing for 30 s. When participants stopped singing, the experimenter indicated that they should continue singing, until 30 s had passed and the screen instructed them to relax for another 2 min.

Before and after the SSST, participants were asked to fill out Likert scales on experienced stress (not analyzed here). During the experiment, the experimenter stayed in the room.

2.4 Data Analysis

Skin conductance data were down sampled to 16 Hz, and processed with Continuous Decomposition Analysis (CDA) as implemented in Ledalab [4]. The peak (phasic) activity was also calculated using Ledalab's Through-to-Peak analysis (TTP). The threshold for peak amplitude was set at .03 μs [6]. CDA skin conductance level (SCL), CDA/TTP mean peak amplitude and CDA/TTP number of peaks were determined for each participant and each of the following 30-s time segments: baseline interval 1 through 4, countdown interval following neutral sentence 1 through 4, countdown interval following the stress sentence in which participants prepared to sing, singing interval and baseline intervals 5 through 8.

The main parameter of interest for all electrodermal variables is the 'stress response' that we define as the value during the stress countdown interval (preparation) minus the value during preceding countdown interval (following the fourth neutral sentence) separately for each participant. Experienced stress may actually be higher during singing itself, but during this interval electrodermal activity will also be affected by speech and other movements of the body.

3 Results

3.1 Stress Response in the Group

Figure 1 through Fig. 3 show respectively SCL, peak amplitude (as determined using (a) CDA and (b) TTP) and number of peaks (as determined using (a) CDA and (b) TTP) in the 14 subsequent 30-s time segments, averaged across participants. All variables show an effect of the stressor: values are higher during the stress countdown interval (preparation) compared to the previous countdown interval (neutral 4). Figure 4 shows density plots of the stress responses (the difference between preparation and neutral 4) for all variables. Results of Wilcoxon signed rank tests on stress responses are given in Table 2. Stress responses are significantly larger than zero for all measures, with all z-scores exceeding 7.4. Note that the error bars (standard deviations) and violins in Fig. 1 through Fig. 3 convey information about the variation in the overall values

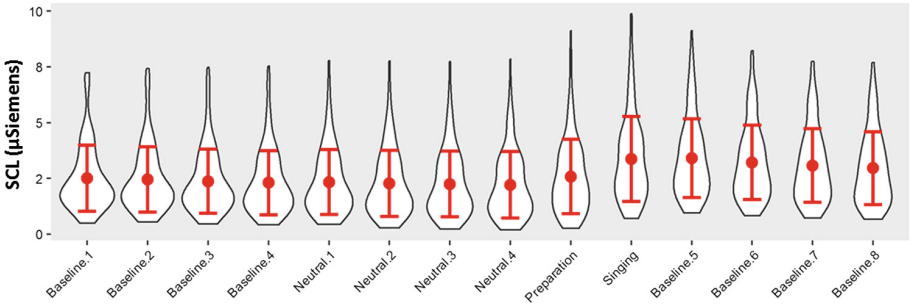

Fig. 1. SCL in the 14 subsequent 30-s time segments, averaged across participants. Error bars represent standard deviations.

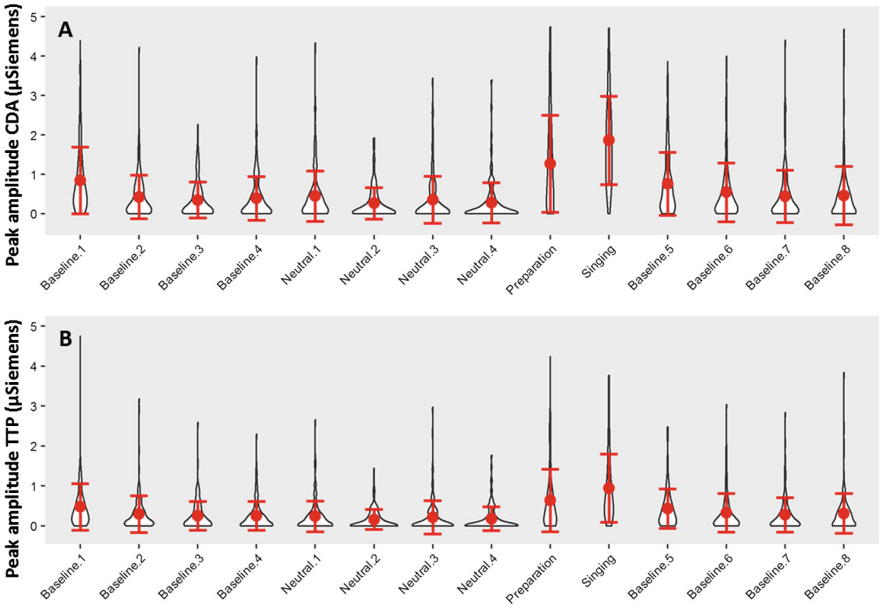

Fig. 2. Peak amplitude (as determined using (a) CDA and (b) TTP) in the 14 subsequent 30-s time segments, averaged across participants. Error bars represent standard deviations.

between participants. This variation somewhat masks the fact that the increase in value from neutral 4 to preparation is very consistent: 90% of participants showed an increase in SCL, 95% in peak amplitude CDA, 89% in peak amplitude TTP, 97% in number of peaks CDA and 96% in number of peaks TTP.

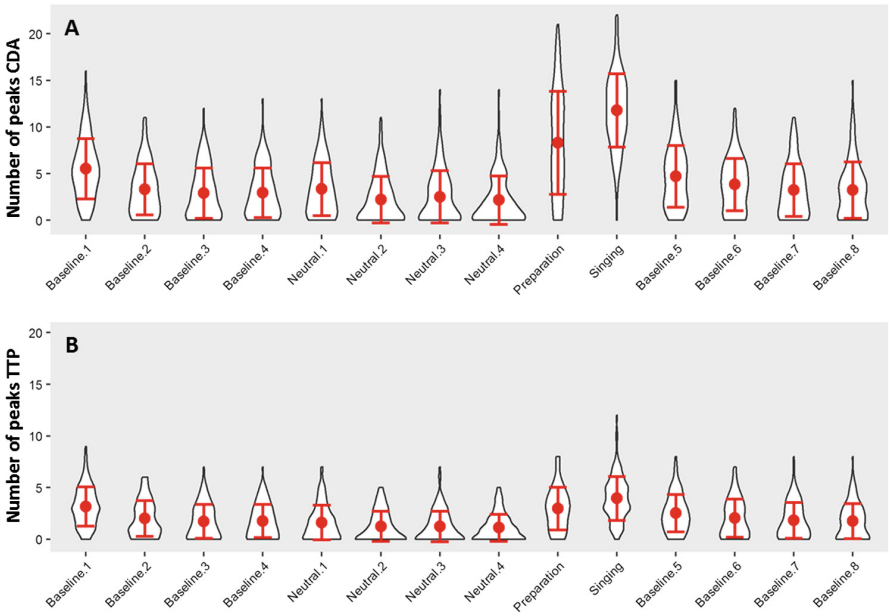

Fig. 3. Number of peaks (as determined using (a) CDA and (b) TTP) in the 14 subsequent 30-s time segments, averaged across participants. Error bars represent standard deviations.

3.2 Stress Response Within an Individual Relative to a Longer Preceding Interval

To determine the sensitivity of electrodermal variables to the stressor within an individual over a longer period of time, we computed an effect size for each variable and each participant by dividing the stress response by the standard deviation of the values of the preceding seven 30-s segments. A high value indicates that an individual's increase of electrodermal activity in response to the stressor is high compared to the individual's natural variability in electrodermal activity in the preceding time intervals. Table 3 presents the mean, standard deviation and range of the individual effect sizes.

Within paired non-parametric tests (Wilcoxon signed rank) on the effect sizes show that the effect size of number of peaks CDA is significantly larger than that of TTP; and that the effect size of peak amplitude CDA is significantly larger than that of TTP. In fact, the effect size of peak amplitude CDA is larger than that of all other measures (all p-values < .01).

3.3 Stressed Versus Non-stressed State Between Two Virtual Groups of Participants

To determine the sensitivity of electrodermal variables to identify whether an individual is in a stressed state, i.e. without knowing his or her baseline, we compared values recorded in the stress countdown interval to values recorded in the preceding countdown interval as if they were coming from two groups of people; a stressed and a

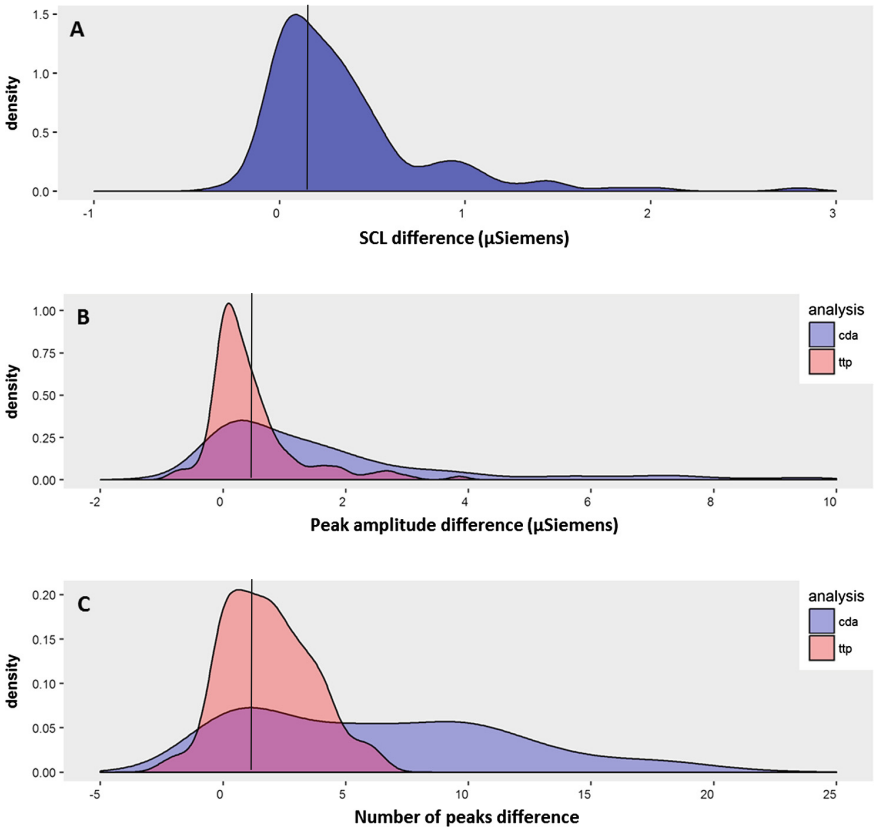

Fig. 4. Density plots of stress responses SCL (A), peak amplitude as extracted through CDA and TTP (B), and number of peaks as extracted through CDA and TTP (C).

Table 2. Results of Wilcoxon signed rank tests on stress responses

	p-value	Signed rank	z-value
SCL	9.985E−20	8169	9.0891
Peak amplitude CDA	2.125E−19	6763	9.0066
Peak amplitude TTP	7.458E−14	6108	7.4796
Number of peaks CDA	1.617E−18	6283	8.7813
Number of peaks TTP	1.633E−16	4993	8.2464

relaxed group (using an independent samples non-parametric test: Wilcoxon rank sum). Not unexpected due to the large variability in SCL baseline between participants, the test on SCL did not reach significance. For all other variables, there was a significant effect (see Table 4).

Table 3. Mean, standard deviation and range of the effect sizes of individual participants

	Mean effect size	Stdev	Range
SCL	2.7419	2.9923	−0.250–5.734
Peak amplitude CDA	6.8739	10.006	−3.132–16.880
Peak amplitude TTP	3.9444	7.230	−3.285–11.174
Number of peaks CDA	4.0635	4.760	−0.696–8.823
Number of peaks TTP	1.8783	2.065	−0.18–3.944

Table 4. Results of Wilcoxon rank sum tests comparing stress countdown intervals to preceding countdown in an unpaired fashion.

	p-value	Signed rank	z-value
SCL	0.057	1903	1.8120
Peak amplitude CDA	5.870E−18	8635	2.2177
Peak amplitude TTP	2.398E−12	7009	2.1172
Number of peaks CDA	3.043E−20	9217	2.2510
Number of peaks TTP	1.344E−14	7702	2.1547

4 Discussion

The simplified and further controlled version of the SSST elicits clear electrodermal stress responses. For almost all participants, higher electrodermal activity was found after presentation of the stress sentence, where this is not due to motor behavior because people are only preparing to sing and do not actually sing or move yet [10]. This further supports the Sing-a-Song Stress Test as a valuable standardized, quick and easy to apply stress induction method. The cognitive tasks as used in this version of the SSST, and the presumed associated arousal, did not result in a noticeable increase of electrodermal activity as indicated by Figs. 1, 2 and 3 (no higher values for the neutral countdown intervals compared to the first four resting baseline segments). Potential subtle effects may have been masked by the observed trend of electrodermal activity to decrease over time.

With respect to sensitivity of the peak variables, CDA outperforms TTP, both for amplitude and number of peaks. This holds true for all three scenarios (overall stress response in a group; stress response within an individual as compared to her or his variability in preceding electrodermal activity over a longer interval; differences between stressed and non-stressed individuals). This is indicated by the finding that z-values always tended to be higher when peak variables were determined using CDA compared to TTP (Tables 2 and 4) and that effect sizes are significantly larger when peak variables were determined using CDA compared to TTP (Table 3). Figures 2 and 3 show that compared to TTP, CDA captures higher values of peak amplitude and (especially) higher number of peaks. The higher sensitivity of CDA for the SSST stressor corroborates findings indicating higher sensitivity for CDA for a short event-related noise paradigm [4].

SCL shows large variation between participants relative to the average increase in SCL due to the stressor (Fig. 1). However, the Wilcoxon signed rank test in Sect. 3.1 shows that the SCL stress response (i.e., the increase of SCL after presentation of the stress sentence compared to the previous count down interval) is comparable, and even tends to be strongest, to the stress response for the peak measures. When examining electrodermal activity over time within a single participant (effect size in Sect. 3.2), SCL is less sensitive compared to the CDA peak measures. Thus, SCL seems to be a relatively variable signal when viewed over a longer time before the stressor. In accordance with this, Fig. 1 shows that at the start of the measurements, SCL is almost at the level of the stress countdown interval. This also holds for number of peaks TTP which accordingly shows the lowest effect size. Peak amplitude CDA looks most stable across the preceding intervals, and also captures some very strong positive responses (see range indicated in Table 3).

When comparing SCL values in the stress 'preparation' interval to the values as recorded during the preceding countdown interval using a test for independent samples (i.e. treating the data as coming from two groups of individuals; a stressed and a relaxed group), the difference in SCL did not reach significance. This means that when the baseline value of an individual is not known, SCL is not suitable to estimate whether an individual is stressed. Consistent with this, Hogervorst et al. [12] found that a measure reflecting SCL did not distinguish between individuals who were about to undergo stressful eye laser surgery, while heart rate related variables did. The other, peak-related variables showed a clearly significant effect (Table 4), indicating that these can be used when the baseline of an individual is unknown.

Overall, our results show CDA peak amplitude to be the most stable indicator of the occurrence of the stressor across scenarios. SCL is an effective measure when a comparison with an individual's immediately preceding baseline is available. If this baseline is not available, SCL is clearly less useful whereas the peak measures (amplitude and number, especially when determined using CDA) still are reliable indicators of stress.

We conclude this paper by pointing out some observations and directions for future research.

All electrodermal variables show higher values during the singing itself compared to the countdown interval before. This could be due to a combination of stronger mental arousal (e.g. the singing itself is scarier than preparing for it), body movement (most notably speech and breathing) and delayed effects of the end of the countdown interval preceding the singing (which may have been most arousing). It would be of interest to tease these factors somewhat apart in future research and analyses.

By specifying the time that participants should sing followed by a resting baseline, the used version of the SSST is also suitable to examine recovery processes. Figure 1 through Fig. 3 suggests an essential distinction between SCL and peak variables: while all variables show a decrease in electrodermal activity, this seems to occur at a much slower pace for SCL compared to the peak variables.

Acknowledgement. We are grateful to Imke Silderhuis, Sacha Jenderny, Steven de Vries, and Laura Duddeck for data collection and preparing the experiment, and Maarten Hogervorst for helpful discussions on this paper. The present study was partially funded by the defense program V1532 AMPERE.

References

1. Rizzo, A., Graap, K., Mclay, R.N., Perlma, K., Rothbaum, B.O., Reger, G., Parsons, T., Difede, J., Pair, J., et al.: Virtual Iraq: initial case reports from a VR exposure therapy application for combat-related post traumatic stress disorder. In: Proceedings of the International Workshop on Virtual Rehabilitation, pp. 124–130. IEEE Press, Washington (2007)
2. Toet, A., Bijlsma, M., Brouwer, A.-M.: Stress response and facial trustworthiness judgements in civilians and military. SAGE Open **7**(3), 1–11 (2017). http://journals.sagepub.com/doi/full/10.1177/2158244017725386
3. Dawson, M.E., Schell, A.M., Filion, D.L.: The electrodermal system. In: Cacioppo, J.T., Tassinary, L.G., Berntson, G.G. (eds.) Handbook of Psychophysiology. Cambridge University Press, Cambridge (2007)
4. Benedek, M., Kaernbach, C.: A continuous measure of phasic electrodermal activity. J. Neurosci. Methods **190**(1), 80–91 (2010)
5. Andreassi, J.L.: Psychophysiology: Human Behavior and Physiological Response, 5th edn. Psychology Press, Taylor & Francis Group, LLC, New York (2007)
6. Boucsein, W.: Electrodermal Activity, 2nd edn. Springer, New York (2012). https://doi.org/10.1007/978-1-4614-1126-0
7. Eisenberg, N., Fabes, R.A., Bustamante, D., Mathy, R.M., Miller, P.A., Lindholm, E.: Differentiation of vicariously induced emotional reactions in children. Dev. Psychol. **24**, 237–246 (1988)
8. Lang, P.J., Bradley, M.M., Cuthbert, B.N.: International Affective Picture System (IAPS): affective ratings of pictures and instruction manual. Technical report, University of Florida, Gainesville, Fl (2005)
9. Kirschbaum, C., Pirke, K.M., Hellhammer, D.H.: The "Trier Social Stress Test"—a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology **28**, 76–78 (1993)
10. Brouwer, A.-M., Hogervorst, M.A.: A new paradigm to induce mental stress: the Sing-a-Song Stress Test (SSST). Front. Neurosci. **8**, 224 (2014)
11. Brouwer, A.-M., Hogervorst, M.A., Holewijn, M., van Erp, J.B.F.: Evidence for effects of task difficulty but not learning on neurophysiological variables associated with effort. Int. J. Psychophysiol. **93**, 242–252 (2014)
12. Hogervorst, M.A., Brouwer, A.-M., Vos, W.: Physiological correlates of stress in individuals about to undergo eye laser surgery. In: Humaine Association Conference on Affective Computing and Intelligent Interaction, pp. 473–478. IEEE Computer Society (2013)