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Metrological evaluation of skin conductance measurements

Jaka Ogorevc *, Gregor Geršak, Domen Novak, Janko Drnovšek

Faculty of Electrical Engineering, University of Ljubljana, Tržaska 25, 1000 Ljubljana, Slovenia

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ABSTRACT

Electrodermal activity is a frequently measured physiological response in various applications. It is also being increasingly used in clinical applications. Numerous published papers report results of skin conductance measurements in absolute values, but few are concerned with the quality of results. This paper describes a procedure for metrological evaluation of skin conductance measurement. Three commercial devices for measuring skin conductance were calibrated by comparison with a precision digital ohmmeter used as a reference. Combined measurement uncertainty of skin conductance meters was calculated by means of uncertainty of reference instrument and uncertainties due to measurement repeatability, reproducibility, resolution and environmental condition. Additionally, a procedure for evaluation of the effect of electrode displacement and electrode gel was shown. A model of finger skin conductance profile was build. Measurement uncertainty analysis showed that contributions due to resolution and sensitivity of the measuring device, usually obtained from specifications, are negligible when compared to uncertainty of measuring method. Our results indicate that measurement uncertainty does not meet target uncertainty requirements for certain applications.

1. Introduction

Skin conductance also known as galvanic skin response or psychogalvanic reflex, is method of exosomatic recording of electrodermal activity by applying external current to the skin [1]. Electrodermal activity is a physiological parameter depending on sweat gland activity. Since sweat gland activity is controlled by the sympathetic nervous system, skin conductance measurement is used as an indicator of psychophysiological arousal.

Skin conductance measurement is most frequently used in psychology, particularly to evaluate emotional arousal [2,3]. It is also used in studies on stress evaluation [4–6] and driver workload [7,8]. It is part of polygraph interrogation methods used in criminology [9]. In psychopathology, skin conductance was reported to predict symptoms of schizophrenia [10,11], instability during relaxation in panic disorder [12], development of anxiety [13], and defensive response of phobic patients [14]. In neurology, it was measured in studies of suppression of skin response in brain infarction [15], altered decision-making in multiple sclerosis patients [16], lack of psychophysiological response to failure of children with attention-deficit hyperactivity-disorder (ADHD) [17], lower electrodermal response to significant stimuli of patients with brain damage [18], impaired fear conditioning in Alzheimer's disease [19], face recognition disorder of patients with Capgras delusion [20], and enhanced psychophysiological response to pain-related words in chronic pain patients [21]. Additionally, skin conductance measurement has been used for evaluation of stroke rehabilitation [22], early detection of cystic fibrosis [23], characterization of the sympathetic arousal in autism [24], reducing seizure frequency in epilepsy [25], investigating depressive symptoms in hyperthyroid patients [26], assessment of food-induced arousal in anorexics [27], detecting processing deficit in emotional reactivity of patients with alexithymia [28], and in alcohol, nicotine and cannabis substance dependence research [29]. It was also proposed as a promising tool in treatment evaluation

* Corresponding author. Tel.: +386 1 4768 245; fax: +386 1 4264 633.
E-mail address: jaka.ogorevc@fe.uni-lj.si (J. Ogorevc).

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of hyperhidrosis [30] and diabetes [31]. Recently, it has also seen use in the entertainment industry [32,33].

Fig. 1 shows the basic principle of skin conductance measurement. In terms of electrical measurements and calibration, it is considered to be a 2-wire resistance measurement. Direct-current voltage *U* is applied between two electrodes [1,34]. Current *I* is measured by a voltmeter as the voltage drop on resistor *R* connected in series with the skin. Skin conductance is the ratio of current *I* and voltage *U*. The problematic issues of skin conductance measurement include choice of measuring site, electrode material, contact resistance between electrode and skin, and applied voltage. Recommended measuring sites for bipolar measurement of skin conductance are distal and intermediate phalanges of fingers, palm (tenar and hypotenar), upper arm, plantar surface of foot [1,6,34–36]. It is also recommended that the electrodes are placed on the same arm or leg to avoid disturbances caused by motion artifact. To achieve better contact between the skin and the electrodes, it is recommended to use electrodes made from silver–silver chloride (Ag/AgCl) with recommended contact area of 1 cm^2 [1,34,35]. Use of electrolyte gel (usually 0.05 M NaCl solution) is also recommended [1,34–36]. Recommended applied direct-current voltage is 0.5 V, which is the most commonly used applied voltage in commercial skin conductance meters [34,35].

To our knowledge there is no published research discussing skin conductance measurements from the metrological point of view in terms of a complete measurement result. Namely, a complete measurement result is not only consisting of the measured value, corresponding unit but also includes the information about the uncertainty of the measurement [37]. Manufacturers of commercial skin conductance measurement devices usually give only information on the measuring range, resolution and sensitivity of the measuring instrument. The product specifications contain no data on measurement accuracy, measuring error or measurement uncertainty. Assuming only the resolution and sensitivity of the measuring device can be considered as measurement uncertainty is highly misleading and incorrect in principle (although commonly perceived). By rule of a thumb, resolution and sensitivity can indeed represent theoretically lowest possible measuring uncertainty, but at least repeatability of the measurement needs to be added to them. With metrological evaluation, like presented in this paper, all major uncertainty contributions are identified, evaluated and estimated. By adding the contributions the resulting combined measuring uncertainty of the measurement can be calculated. Thus establishing traceability to the International system of units SI. It enables accuracy, reliability and comparability of measurement results of various laboratories throughout the world. This is doubly important since skin conductance measurements are increasingly used in clinical applications and thus help physicians make important decisions about patient diagnosis and treatment. Requirements of medical staff and psychologists are reflected in the target uncertainty, which is defined as the upper limit of measurement uncertainty and determined based on the intended use of measurement results. In case of skin conductance, 0.05 μS can be considered as the target uncertainty. This value is used in signal processing of skin conductance measurements as the lowest value for skin conductance response determination [1,3,5,36]. Skin conductance response represents a phasic electrodermal activity. It is defined as significant fast fluctuation of skin conductance with amplitudes 0.05 μS or higher perceived less than 3 s after stimulus occurrence.

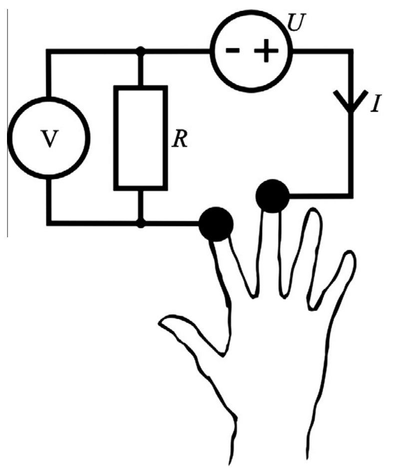

Fig. 1. Basic principle of skin conductance measurement. Direct-current voltage *U* is applied between two electrodes (black circles). Current *I* runs through the skin and is measured indirectly as voltage drop on resistor *R* using a voltmeter V.

Measurement uncertainty generally consists of three major parts: uncertainty of measuring instrument, measuring method and measurement environment [38].

Almost all papers discussing skin conductance measurements describe the measurement results in absolute terms using an appropriate measurement unit (in the case of skin conductance, most commonly μS – microSiemens), but accuracy and consequently reliability of reported measurement results is seldom questioned and investigated [6]. When comparing reported measurement results, absolute values of skin conductance are compared. However, reliability of such comparison is questionable if information about measuring error and measurement uncertainty is not known. Metrological evaluation of skin conductance measurement is necessary for reliable and comparable results. This study describes a procedure for metrological evaluation of skin conductance measurements. Measurement of conductance is basically measurement of electrical resistance, which is an inverse of conductance. Thus, the measuring instruments used are ohmmeters. In order to achieve metrological evaluation of skin conductance meters, calibration of measuring instruments was performed in accordance with guidelines on the calibration of digital multimeters [39].

In this paper a procedure for metrological evaluation of skin conductance measurement is proposed. The procedure is based on calibration by comparison method of three commercial skin conductance measurement devices. Measurement uncertainty budget was calculated for all measurements. In addition, for the purpose of uncertainty budget estimation influence of the measuring site was investigated.