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# Electrical measurement of sweat activity

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**Abstract**

A multichannel logger for long-term measurements of sweat activity is presented. The logger uses skin surface electrodes for unipolar admittance measurements in the stratum corneum. The logger is developed with emphasis on clinical use. The portability of the logger enables recording of sweat activity under circumstances such as daily errands, exercise and sleep. Measurements have been done on 24 healthy volunteers during relaxation and exercise with heart rate monitoring. Recordings of sweat activity during sleep have been done on two healthy subjects. Early results show good agreement with the literature on sweating physiology and electrodermal activity. Results are presented showing measurements related to physical exercise, dermatomes, distribution of sweat glands and sympathetic activity. This study examines the normal sweating patterns for the healthy population, and we present results with the first 24 healthy volunteers. Comparing these results with similar measurements on hyperhidrosis patients will make it possible to find the most useful parameters for diagnosis and treatment evaluation.

Keywords: sweat, skin conductance, hyperhidrosis, sympathetic activity, sweat glands

## 1. Introduction

Electrodermal measurements have been done since the 1880s with the pioneering studies of Féré (1888) and Tarchanoff (1889). What is known as the psychogalvanic reflex was found by Veraguth (1907). The sweat glands were identified as the seat of the 'psychogalvanic phenomena' in 1930 by McClendon and Hemingway (1930), and a palmar galvanic test was used for indicating sweat secretion in the same year by Wang and Lu (1930). Later, electrodermal measurements became a common tool within the field of psychophysiology (Martin and Venables 1980). Sweat production as moisture emitted from skin can be measured quantitatively in nanoliter per minute using the trans-epidermal water loss (TEWL) method. This is, however, not the same as the sweat production from the gland, or sweat activity defined as the filling of sweat in the duct and the reabsorption process. The electrical measurement is related to the filling and reabsorption processes, and thus is more directly related to the glandular activity. Due to differences in methods and analyses in electrodermal measurements, there is still no established unit relating electrical measurements to sweat activity. At least a dozen fundamentally different methods of measurement have been presented in the early literature (Landis and Forbes 1933). Depending on the electrode configuration, type of electrodes, excitation frequency and signal extraction, other factors than the sweat activity may dominate the measurement, e.g. electrode polarization or contributions from the skin moisture content. Krogstad *et al* showed that palmar dc skin conductance levels showed weak correlations with the perceived sweating (Krogstad *et al* 2004). It is also important to emphasize that the skin conductance levels are not in direct correlation with the sweat production or the evaporation from skin, but rather the sweat activity with the filling of the sweat ducts and the reabsorption process. It may be possible to find parameters from the skin conductance curves which are possible to calibrate with respect to the quantity of sweat production or the perceived levels of sweat activity. Such a parametrization from a curve into a few numbers would be ideal in regard to diagnostic purposes.

The stratum corneum (SC) is the outermost layer of the skin epithelium, consisting mostly of dead skin cells in a thickness of generally 15–20 layers. This keratinized tissue has a very high ionic impedivity compared to the deeper layers of the skin. The impedivity in the SC varies by the moisture content, and is largest on the surface with direct contact to the ambient humidity. The ionic shunts formed by the sweat ducts have a large influence on the admittance of the outer skin layer. A doubling of the SC admittance can be seen within a few seconds in response to the filling of the sweat ducts (Grimnes 1982). Sweat is an electrolyte solution, and the filling of the sweat ducts gives a mainly conductive contribution to the electrical admittance (Grimnes 1982), while the capacitive part represents the SC moisture content (Martinsen *et al* 1995, 1998, Martinsen and Grimnes 2001). Using these presumptions, we can measure the filling of the sweat ducts by performing an ac conductance measurement. The dc conductance method is unable to cancel out endosomatic potentials (Jabbari *et al* 2007) generated by the skin, and the electrode polarization is much larger than for measurements using higher frequencies.

An electrical method for measuring sweat activity enables the construction of a small, portable and battery-powered unit for continuous and long-term measurements. Such a device can assist in treating patients with diseases where elevated sweat activity is the disease itself (i.e. primary hyperhidrosis), or if the sweating occurs as a result of another medical condition (secondary hyperhidrosis). Hyperhidrosis has a prevalence of 2.8% in the US (Strutton *et al* 2004). In addition to diagnosis, the treatment evaluation is also a challenge with this patient group, especially regarding the sympatectomy procedure. The most common problem is compensatory sweating post-operatively, and there is a lack of a standard definition of compensatory sweating and an accurate objective method for its measurement (Ojimba and Cameron 2004). A reduced sweat activity or response can be used as indicators for diabetic neuropathy (Hoeldtke *et al* 2001, Markendeya *et al* 2004) and other diseases afflicting the autonomous nervous system such as Ross syndrome (Chemmanam *et al* 2007) where sympathetic skin responses are reported to be absent in the affected segments. Defective sweating is also an inseparable and major component of the constellation of symptoms that diagnose cystic fibrosis (Quinton 2007). For palmar hyperhidrosis, little is known about the daily pattern of sweating (Krogstad *et al* 2006) and there is no consensus based on objective criteria as to when treatment should be given (Krogstad *et al* 2004). The iodine starch test, gravimetry, evaporation and skin conduction have all been proposed as objective estimates, but are limited to controlled laboratory research (Krogstad *et al* 2006). Hence, there is a need for portable equipment for the long-term measurement of sweat activity. This paper presents such a solution, enabling 24 h assessment of a patient's condition during different activities. Preliminary results are presented and demonstrate sweat activity related to different physiological phenomena.

The aim of this study was to gather data on sweat activity related to different physiological phenomena in healthy subjects. These data will then be used as a normal material for comparison with measurements on patients.

## 2. Materials and methods

A unipolar ac conductance measurement using constant voltage applied to the stratum corneum beneath a measuring electrode was used (Tronstad *et al* 2007). In order to have the measurements dominated by the impedance contribution from the SC and not the viable skin, they were done at a low frequency as described by Martinsen *et al* (1999). The excitation voltage was 30 mV as a compromise between signal to noise ratio and system linearity. Based on this method, a medical device for measuring sweat activity was developed. For clinical use, a number of demands had to be considered. For evaluating the sweating pattern of a patient, a logging of measurements taken at several skin sites over a period of up to 24 h of different activities is of interest. This requires a high degree of portability, making a battery-powered pocketsize logger the most appropriate solution. For medical safety, the patient shall not be directly or indirectly coupled to ground but at the same time continuous monitoring on a host PC is desired. These demands were solved by the use of wireless (RF) communication between the logger and the host PC. Hence, the electronics challenge was to minimize the size and current consumption. For this purpose, a microcontroller was used to perform most of the tasks digitally by the method described by Tronstad *et al* (2007), reducing the number of components needed and the total current consumption.

To measure at several skin sites simultaneously, the logger was equipped with four channels. Complete channel separation was achieved by implementing an ADC (analog to digital converter) with an onboard multiplexer and by adding circuitry for each current-to-voltage conversion and filtering. Measurements are then taken serially by multiplexing between the measuring channels.

For non-volatile data storage in the logger, an EEPROM (electrically erasable programmable read-only memory) was implemented with the capability of storing data for over two days when one measurement is taken per minute. Figure 1 shows the complete measurement system operated by the microcontroller. The SPI, UART and GPIO functions control and communicate with the ADC, EEPROM and the RF module, while the PWM (pulse-width modulation) module generates the excitation signal together with a low-pass filter feeding the excitation circuitry (E).

Display on the logger unit would be impractical considering the size and current consumption, so an RF transceiver was implemented to export the data to a monitoring host. Software was developed for a PC to be able to monitor the logger, download data stored on the logger and display saved files with additional functions. A series of five prototypes was produced and has passed the internal approval for clinical research use at Rikshospitalet, Norway.

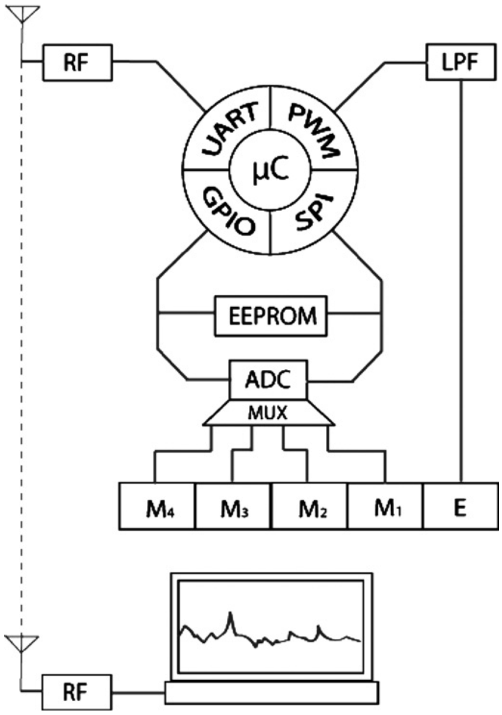


**Figure 1.** Measurement system with four measuring channels, data storage and host communication.

The size of the prototype of the logger is of dimensions 157 mm × 95 mm × 33 mm, which fits into a pocket or can be comfortably carried attached to the belt. If there is use for a smaller model, a vast size reduction is possible due to recent advances in microchip technology such as IDC (impedance to digital converter) chips.

Measurements were done during relaxation and exercise on 24 healthy Norwegian subjects (15 M, 9 F) between the ages 18–67 who gave informed consent. Recordings of sweat activity before, during and after sleep were also done on two healthy Norwegian subjects. For measuring the heart rate of the subjects during the experiments, a commercial heart rate monitor (Polar RS400) was used.

## 3. Results

The sweat activity measurements were monitored directly on a PC with a wireless connection, or the test subject carried the logger with him/her and uploaded the logged data later. The results presented are selections of typical measurements from experiments done on the healthy subjects.

Figure 2 shows results from the logger during a period of relaxation, then intense physical activity (chin-ups) for half a minute followed by relaxation again. Electrodes were placed on the abdomen, the hypothenar area of the palm, the neck and the forehead. Heart rate was also recorded for comparison with the sweat activity measurements. The dashed box indicates the time of the physical activity.

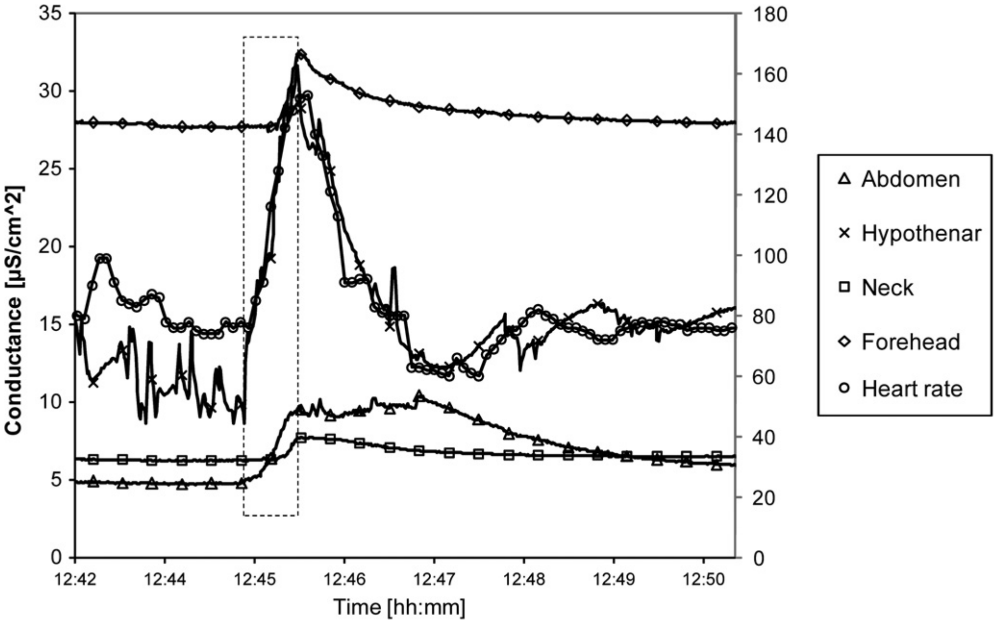


**Figure 2.** Skin conductance and heart rate of a 28-year-old male in response to strenuous physical activity. The dashed box indicates the period of the physical activity.

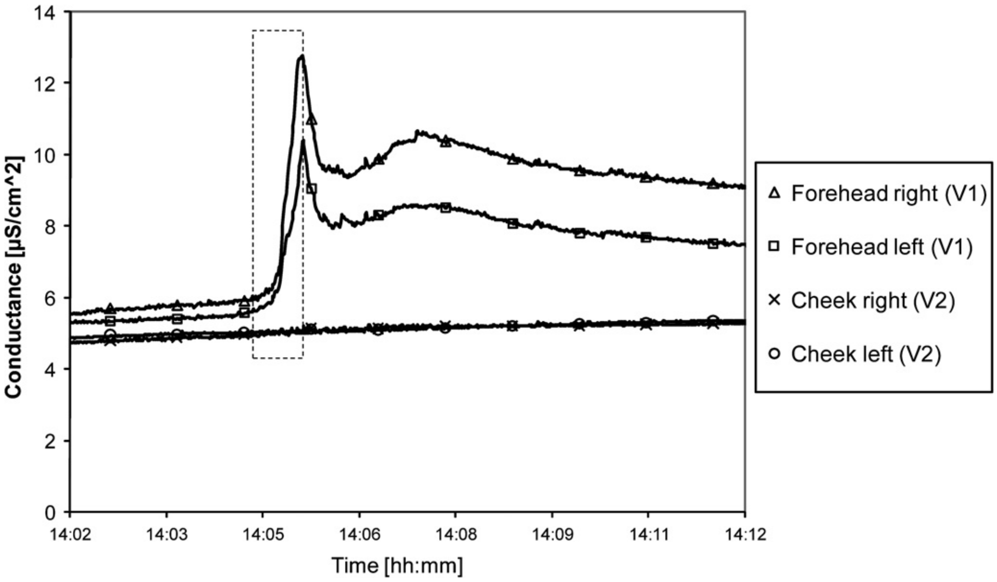


**Figure 3.** Skin conductance during squats measured at V1 and V2 dermatomes on a 67-year-old male.

Figure 3 shows measurements done during the exercise (10 deep squats without extra weight) at the forehead and the cheeks, which belong to two different dermatomes. The sweat activity at the forehead, which belongs to the V1 dermatome, has a strong response to the

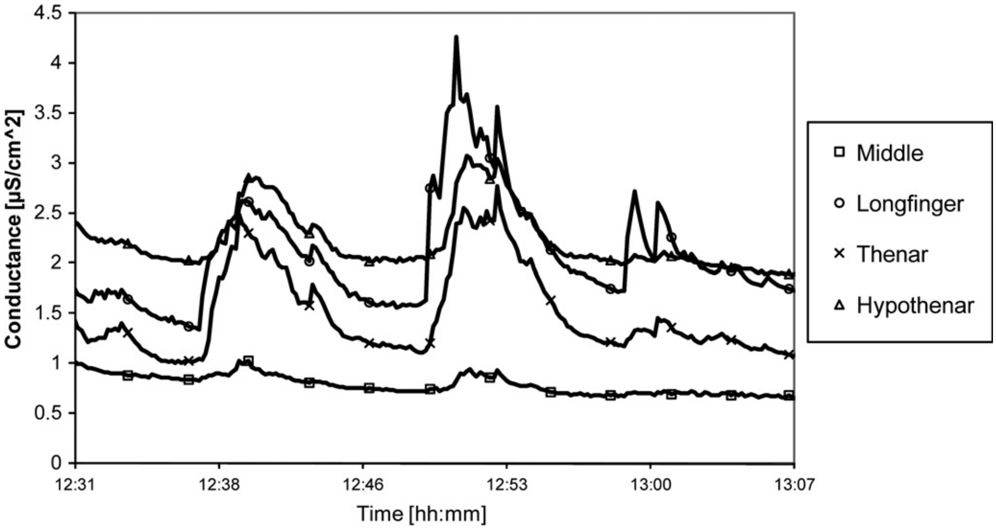


**Figure 4.** Skin conductance at the middle of the palm, the tip of the long finger, the thenar and hypothenar areas of the palm of a 67-year-old male.

squats, while the sweat activity at the cheeks, belonging to the V2 dermatome, shows no response.

Figure 4 shows a typical measurement done at different sites within the palm with a stronger response in the distal palm than at the medial palm.

Figure 5 shows a sweat activity recording before, during and after sleep, measured at three palmar sites and at the neck.

## 4. Discussion

The presented results show that the method is sensitive to different characteristics of sweating-related physiology such as exercise response (figure 2), innervations of sweat glands with respect to dermatomes (figure 3), sweat gland density (figure 4) and sympathetic activity (figure 5).

The curves within the box in figure 2 show differences both in the magnitude and the delay of the response to the physical activity. The hypothenar measurement clearly shows the most direct response and a strong correlation with the heart rate curve. This correlation has been observed frequently in our measurements and may be explained by both having sympathetic innervation, and that the most numerous sweat glands are found on the palms and soles in adults (Montagna and Parakkal 1974). Sweating from muscular exercise is a combination of thermal and mental sweating (Kuno 1956), so none of the curves can be claimed to represent purely thermoregulatory sweating. There are large differences in the number of sweat glands per skin area depending on the skin site (Montagna and Parakkal 1974), and different skin areas classified as dermatomes are innervated by different dorsal roots. The curves in figure 3 are initially on an equal level, but upon physical activity they show a clear difference in response between the two facial dermatomes V1 and V2. Even within the palm, significant differences can be seen between skin sites, as shown in figure 4 where the curve from the middle of the palm is almost flat and nonresponsive compared to the other curves. This is

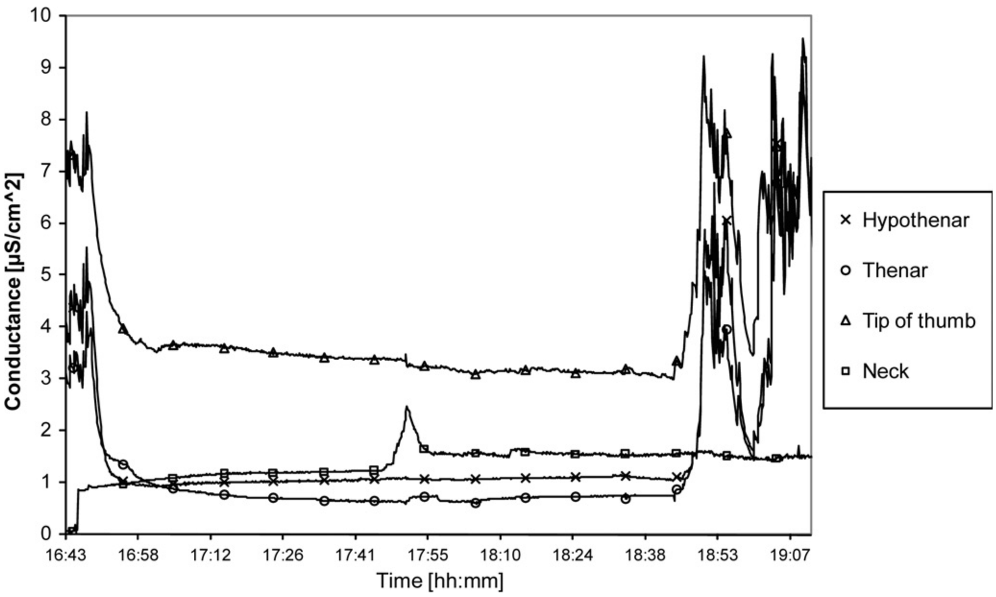


**Figure 5.** Skin conductance before, during and after sleep measured on a 27-year-old male.

supported by the findings of Freedman *et al* (1994), who reported a larger count of open and total sweat glands at the distal palm than at the medial palm.

Contrary to sweating at other sites, the palms and soles produce sweat only in response to mental or sensory stimulation and not at all to thermal agents (Kuno 1956). This type of activity is often referred to as exosomatic electrodermal response (EDR), and is usually present at some level during a conscious state of mind, but disappears during sleep (Kuno 1956). From figure 5 it can be seen that in the initial awake period, the palmar areas show frequent EDR activity while the neck area is inactive. During the onset of sleep, all the palmar curves flatten out, and the neck curve remains unchanged except for one unexplained peak. The palmar EDR activity resumes upon awakening.

There is little literature available regarding sweating patterns of healthy people, and the authors have seen large interindividual variations in measurements done so far on healthy subjects under relaxation, exercise and heat exposure. This creates a need to gather more data on healthy volunteers of different sex, age, heritage and activity levels in order to determine normal levels for the healthy population at different skin locations. This material can then be used to compare with similar measurements in hyperhidrosis patients in order to find the best distinguishing parameters of the curves.

Even though testing has now been done on healthy controls, our method has not yet been tested on patients. The method has been correlated to heart rate as a physiological parameter, and further studies can be done with, e.g., body temperature or neural stimulation as physiological references. Although the TEWL methods are measuring a different process of the sweating, comparing the methods can yield a relation between the level of sweat activity in the ducts and the onset of evaporation.

Although the method is suited for use in the hospital, some care should to be taken when used together with other bioelectrical medical equipment such as ECG due to possible interference problems.

## 5. Conclusion

A portable four-channel logger for the long-term measurement of sweat activity has been developed. Measurements show a relation to the physiological parameters such as the intensity of physical activity, skin innervations, sweat gland distribution and sympathetic activity. Initial results on healthy individuals show large interindividual differences. Based on normal material gathered from healthy subjects, comparison with similar measurements on hyperhidrosis patients can be done in order to find the best distinguishing parameter to be used for the diagnosis and treatment evaluation of the condition.

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