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The early days of electrodermal activity

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Título: Los primeros días de la actividad electrodérmica.
Resumen: Este artículo enfatiza las etapas principales del descubrimiento de uno de los marcadores autonómos más destacados de las expresiones mentales, la actividad electrodérmica (EDA). La contribución de las escuelas de fisiología francesa y alemana, orientada por las necesidades clínicas y el deseo de conocer más sobre los mecanismos fisiológicos, constituyen las primeras raíces de dicha actividad. En este marco, Féré y Tarchanoff, descubridores franceses y rusos respectivamente, establecieron el vínculo entre la actividad mental y la EDA, por un lado, y sentaron las bases metodológicas de la utilización moderna de este neuromarcador, por el otro. Este legado, asociado con medidas neuronales centrales, promete un futuro en expansión en neuropsicología, psicopatología, neurología, criminología y en neurociencia cognitiva y afectiva.
Palabra clave: Actividad electrodérmica. Conductancia cutánea. Potencial cutáneo. Sistema nervioso autónomo. Emoción. Féré. Tarchanoff.

Abstract: This paper emphazises main steps of the discovery of one of the most salient autonomic markers of mind expressions, the electrodermal activity (EDA). The contribution of French and German schools of physiology, aimed by clinical needs and the desire to know further about physiological mechanisms, constitutes the very early roots of such activity. In this frame, Féré and Tarchanoff, respectively a French and a Russian discoverers, established the link between mind activity and the EDA on the one hand and laid the methodological foundations of modern utilisation of this neuromarker on the other hand. This heritage, associated with central neural measures, is promised to an expanding future in neuropsychology, psychopathology, neurology, criminology and in cognitive and affective neuroscience.
Keywords: Electrodermal activity. Skin conductance. Skin potential. Autonomic nervous system. Emotion. Féré. Tarchanoff.

Introduction

The electrodermal activity (EDA) is currently considered as one of the most important neurophysiological indices of emotional and cognitive functions[1]. EDA corresponds to electrical skin variations related to the sweat glands functioning and has been used as a reliable physiological indicator of central activations. The very early electrodermal recordings were carried out at the end of the XIXth century by Féré and Tarchanoff, respectively a French and a Russian researchers. Their experiments, conducted independently, have created the foundations of modern recording techniques of EDA. The contribution of these researchers also revealed the strong scientific interactions through European physiological institutions, particularly involved to find very early markers to reliably measure mental functions. Before considering the early roots of the EDA, we recall below some characteristics underlying this physiological activity as they are known in our days.

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1. The electrodermal activity: An autonomic window on the mind

The EDA is the electrical expression of the activity developed by the eccrine sweat glands, mainly located in deep layers of palmar and plantar skin. These glands are under the exclusive control of the sympathetic branch of the autonomic nervous system. Through the sympathetic control, sweat production and consequent EDA variations express activations produced by brain areas. EDA thus reveals high functions subtended by the brain functioning, a sort of body signature allowing access to the mind space.

In experimental practice, EDA is usually recorded, thanks to different techniques, like dermal conductance or potential, and using electrodes placed in contact with the skin of index and middle fingers. Following recommendations of Fowles et al. (1981) and Boucsein et al. (2012), the EDA is generally recorded as cutaneous conductance variations and expressed in terms of electrodermal responses, known as skin conductance responses (SCRs; see Fig 1A-B). The amplitude of SCRs is strongly sensitive to activations generated by the central nervous system and transmitted to eccrine sweat glands by sympathetic fibers. Consequently, SCRs characteristics reveal mind functions requiring central activations like novelty, attention, action, memory or emotion. In this frame, SCRs are now recognized as a good marker of the cerebral impact of emotion on the body. Indeed, during emotional stimulation, SCRs amplitude increases with the subjective assessment of the emotional activation of the stimulus, regardless of emotional valence (Lang et al., 1993; Bradley et al., 2001a). Therefore, SCRs constitute a reliable and robust index of the somato-visceral impact of brain activations engaged in the processing of emotional information (Sequeira et al., 2009).

In a more general way, the EDA is considered as a very useful physiological activity, highly sensitive to any content with a specific signification for an individual. For this reason, the EDA constitutes one of the best physiological *windows* of brain activity. Indeed, for more than a century, the EDA has been used as a tentative neural index of cognitive and emotional functions in healthy and pathological individuals. In this frame, the EDA recording has been extensively recorded in rats, cats, monkeys and humans (see Sequeira and Roy, 1997 for a review). Thus, the generalized utilization of the EDA among modern neuromarkers in the field of neuroscience (e.g.), greatly increased the researcher's interest to elucidate and understand early steps of electrodermal recordings.

2. Early observations on electrical skin variations

The very early history of electrodermal activity begins probably with experiments performed by DuBois-Reymond (1849), in Germany; participants put either hands or feet into a zinc sulfate solution and this author observed an electrical current going from the limb at rest to the other one which was voluntary contracted. He explained this phenomenon as corresponding to muscle action potentials. Three decades later, Hermann & Luchsinger (1878), carried out a first experiment in which they showed a link between the sweat gland activity and the existence of a current flow, recorded through the skin cat's paw. In Paris, one year later, Vigouroux (1879) observed that different doses of anesthesia modified the psychological reactivity and induced skin current variations in hysterical patients. This author explained such variations as being due to the vascular conductivity. Also in humans, Hermann (1882) described skin currents, particularly intense in areas able to easily produce sweating, like palms and fingers, when participants execute movements similar to those executed by subjects of Dubois-Reymond, in 1849. On the basis of this experimental paradigm, Hermann, for the first time, proposed the implication of sweat glands to explain variations of skin currents. In fact, such currents were classically considered as the result of muscular or vascular activities, which could be modulated by the autonomic control of blood flow. Thus, the Herman's proposition about the potential role of sweat glands was an essential step in the way to link these glands to electrodermal phenomena; however, at this stage, proofs linking sweat glands to the EDA and the EDA to brain functions remained to be found. In this frame, experimental arguments brought by Féré (1888) and Tarchanoff (1889) will constitute a determinant contribution.

3. Féré's contribution: Solving clinical issues

In Paris, the medical environment, sustained since Cabanis (1757-1808) and afterwards through Pinel (1745-1826), developed close links between emotional shocks and mental disorders. However, after 1870's, new theoretical and therapeutic trends appear at the hospital "La Salpêtrière", still in Paris. Indeed, at that period, Charcot (1825-1893) was appointed as the new director (1862) of Salpêtrière's clinical department; between 1881 and 1887, Féré (1852-1907) became member of the same department where he presented his medical doctorate, in 1882. During this period, Charcot's greatly influenced Féré's scientific orientations to the psychological field, such influence mostly corresponding to the idea that the mental pathology was favored by emotional vulnerability. Concomitantly, there were significant scientific progresses related to the physiology of emotions. Firstly, there was an increasing transfer of electrical phenomena knowledge from the physics to the physiology; this will gave rise to a new discipline, the electrophysiology, which became an essential tool for early physiological and psychophysiological explorations. Secondly, at the same time, Bernard (1813-1878) was looking for *physiology of emotions*, through researches about the *autonomic nervous system.*

3.1. Charcot's influence at «La Salpêtrière»

The Charcot's influence at «La Salpêtrière» was marked by a positivist attitude by which the Psychology was considered as a branch of Physiology. In this context, the Charcot's research program, mainly focusing on hysteria, was based on two main orientations. The first postulates that emotions could induce organic lesions and, by this way, generate mental disorders like hysteria. Consequently, it was necessary to find objective markers revealing the mental impact of emotions and, finally, to be able to classify different types of patients. In coherence with this orientation, Charcot asked Féré to evaluate available knowledge about emotions and to quantify the impact of physical and emotional stimulations in the genesis of mental pathology, particularly hysteria. The second idea was based on the belief that electrophysiological techniques could be used as interesting means for diagnosis and therapeutics. Thus, both ideas will orient Féré's work and future issues about the discovery of skin electrical variations to different kind of stimulations.

3.2. Féré's approach: Emotions and electrical skin variations

In this context, enriched by recent developments of electrophysiological techniques, the Féré's approach was however limited by conceptions still strongly linked to the clinical practice. Indeed, he considered that there was no need of statistical procedures because clinical facts present a high degree of variability and are inherent to individuals and specific circumstances. In addition, Féré did not believe on the possibility and interest to transfer data from normal subjects to patients. Despite these methodological restrictions, Féré's environment presented a rich variety of technical tools to go further on physiological exploration, like dynamometer,

pneumograph, tensiometer, plethysmograph, etc. In particular, Féré could use until 15 techniques to identify physiological markers of emotions.

In this frame, the first contribution of Féré linking emotions and body electrical activity was published in 1888 (Société de Biologie, January 14th, 1888: *Note sur des modifications de la tension électrique, dans le corps humain).* In this pioneer publication, he wrote: *«…local modifications of tension under the influence of peripheral excitations or emotions …this supposes that the organism can produce electrical activity»*. This publication will originate a sustained debate about the electrical nature of recordings carried out at skin surface. Vigouroux, in a paper published one month later (Société de Biologie, February 11th, 1888) assumed a clear opposition to the explanation based in the electrical nature of recordings carried out at skin surface: *«… the existence of electrical charges at the skin surface remains to be demonstrated …»*. In the opposite direction, and in the same publication issue, D'Arsonval (Société de Biologie, February 11th, 1888) confirms, in spite of some critics, the reality of electrical skin variations linked to sensory stimulations. Finally, in early March of the same year (Société de Biologie, March 3rd, 1888: *Note sur des modifications de la résistance électrique sous l'influence des excitations sensorielles et des émotions),* Féré expressed, for the first time, the link between emotion and electrical skin variations: *«…several kind of sensory excitations (visual, auditive, taste, olfaction) … and emotion … induce a rapid increase of current conductance (at the skin level)…»,* even if such link is not specific to emotion. At this stage, both Féré and D'Arsonval tried to explain respectively new observed facts: *«…the organism is able to produce electrical activity»* and *«…excitation modifies the hygrometric state of the skin»*. Here begins the idea of promising relationships between emotion, sweating and electrical skin variations.

4. Tarchanoff's contribution: Exploring physiological mechanisms

Tarchanoff was born (1846) in Tbilissi (Georgia) and appears as a highly colored personage. For instance, in the scientific literature, his name had been written as thirteen different forms. He expressed an extended scientific curiosity, developed rich relationships with most representative European laboratories in Physiology and was affiliated with the French *Société de Biologie.*

Tarchanoff integrated the Russian team of Sechenof, recognized as an expert in the field of electrophysiology, and presented his medical doctorate in 1871. Some years later (1877), Tarchanoff became the successor of Cyon at the Chair of Physiology of the University of St. Petersburg. During next years, he travelled through Europe and visited France, Germany and Italy. In particular, he met Dubois-Reymond and Hermann in Berlin and Bernard in Paris and developed local scientific collaborations, exploring several aspects of the animal physiology related to batrachians, birds, etc. In next years (1880-1886) his scientific interests became more focused on human physiology (heart rate, etc.) and psychology.

In 1889, appeared the first publication in «Messager» (St. Petersburg) in which the main discussed topic was similar to that previously published by Féré, in 1888. Later in the same year, Tarchanoff presented at the Société de Biologie (June 29th, 1889) a communication entitled: *«Décharges électriques de la peau de l'homme sous l'influence de l'excitation des organes des sens et de différentes formes d'activité psychique»*. This title strongly matches with that of Féré, presented at the same society on March 3rd, 1888. Finally, a longer version of the Tarchanoff's work was published in Pflüger's Archiv, in 1890.

It should be emphasized that Féré and Tarchanoff's publications differ significantly in terms of experimental approach. Contrary to Féré, Tarchanoff detailed experimental steps, describing carefully the material used, like the galvanometer or recording electrodes. In the same vein, he chose sensory (hot or cold water, pain, auditory, cry, taste, olfaction) and mental (calculations, fear, joy, etc.) stimulations, applied during experiments. In addition, given references are mainly related to German authors (e.g. Hermann).

In conclusion, Féré and Tarchanoff followed different ways to analyze and interpret similar physiological variations: Féré, influenced by the French school, assumed a clinical approach and explore individual observations; Tarchanoff, influenced by German neurophysiology, adopted a scientific approach, based on experimental steps. Despite such differences, both authors have been able to build a common and an inseparable scientific heritage, based on relationships between nervous system activity, sweat glands and associated skin electrical variations.

5. Two pioneers: A complementary heritage

Some years later (1892), Féré synthetized his work in a book entitled *«Pathology of Emotions»*. Curiously, the recording of electrical variations of the skin appeared as a method among others and no reference was given to the Tarchanoff's work. Moreover, since that date, no more work was carried out by Féré on the electrophysiology of the skin and emotion. This could be explained by the fact that Féré had no specific competencies in electrophysiology. In addition, the installation of Janet as the official successor of Charcot at "La Salpêtrière" and the new position of Féré at Bicêtre hospital (1887), certainly contributed to reinforce the early clinical interests of Féré. In this context, emotional states were analyzed as potential determinants of health modulations and electrical variations of skin henceforth considered as having a limited interest for clinical purposes.

Following the Tarchanoff's communication of 1889, in which the Féré's work was not cited, there was no reaction from the scientific community. This communication closed the cycle of the methodological discovery of the EDA and Tarchanoff followed other scientific orientations. Thus, except a communication at the International Congress of Medicine (1894, Roma), related to music influences on skin elec-

trical variations, Tarchanoff pursued known research activities in several topics (e.g. «…hallucinations …in frogs …») until 1900. In particular, since 1896, at St Petersburg, his new scientific interest was focused on physiological effects of X-ray, becoming a recognized specialist in this field.

Finally, although Tarchanoff initiated a significant technical background for the future of the electrodermal recordings, this contribution was just a step in his scientific career, as the Féré's contribution was for his clinical practice. Both pioneers died in 1907, ignoring thus the emerging interest of their scientific contribution, applied to explore normal and pathological mechanisms linked to the physiology and the psychology.

5.1. Electrical variations of skin along the XXth century

The period 1904-1909 brought new avenues for the knowledge and applications of electrical variations of the skin. This was due to the contribution of several authors: Müller, Veraguth, Jung and Peterson. More precisely, the rebirth of the interest for cutaneous electrical signals corresponds to the work of Veraguth about the Psychogalvanic reflex, published in 1909 as *"Das Psychogalvanische Reflexphenomen"*. At the same time, the publication of major works on *«galvanometer and emotions»* (Peterson, 1907; Peterson and Jung, 1907) initiates a new era for the international career of electrodermal signals as innovative tools for the exploration of emotions and the unconscious.

The XXth century, through an important contribution of animal and human experimental research, will be a long and rich period in the comprehension of electrodermal signals. The diversity of methods to record electrical skin variations led to a confused way to name these variations. Thus, as previously indicate, the term "Psychogalvanic reflex", appeared with Peterson and Jung (1907) and renamed by Veraguth (1909) as "galvanic skin reflex" (GSR), remained in most databases until our days. Meanwhile, and waiting for an international nomenclature, electrical skin variations had been identified as: "skin potential reflex", "neuro-galvanic response", "skin potential response", "skin resistance response", "skin conductance response", "electrodermal response" (Ruckmic, 1933). Finally, in 1981, the term "Electrodermal Activity" (EDA) was adopted as an international standard designation to identify spontaneous and induced electrical skin activity, recorded thanks the use of several techniques able to measure potential, resistance, or conductance electrical variations of the skin (Fowles et al., 1981).

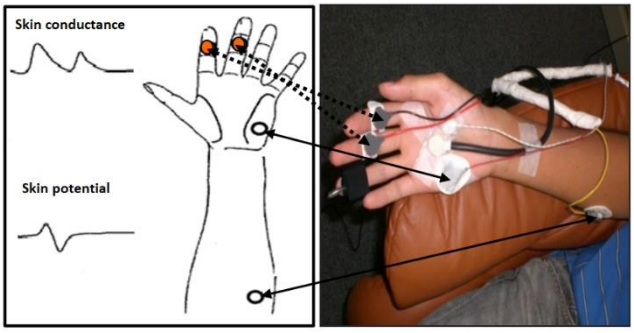
5.2. Féré's methodological heritage: Skin Conductance technique

The Féré's contribution for EDA recordings originates the current exosomatic techniques (skin conductance, SC; skin resistance, SR; skin impedance, SI; skin admittance, SA). These techniques allow to record electric variations of the skin induced by an external voltage applied to the skin surface, as it was later explained on the basis of the Ohm's law. Indeed, this law shows that a constant voltage (0.5 V to 1 V) applied to the skin allows to record variations in the intensity of the external current which depend on the skin resistance. The SC is the most used method for recording electrodermal measures (Fig. 1A-B): the skin conductance level (SCL), a tonic measure of spontaneous sympathetic traffic; the skin conductance responses (SCRs), phasic measures of sympathetic discharges following discrete stimulations. Considering several physical principles and advantages and disadvantages of the various recording techniques, the SC became the international recognized method for recording EDA (Fowles et al., 1981; Sequeira et al., 2009; Boucsein et al., 2012).

5.3. Tarchanoff's methodological heritage: Skin Potential technique

The Tarchanov's contribution gave origin to the current skin potential (SP) technique which allows to record potential differences between two skin sites, one active and the other inactive (Fig. 1A-B); this is an endosomatic method because, in contrast with exosomatic techniques, does not require an external voltage applied to the skin. The SP allows the acquisition of two measures: skin potential level (SPL) and skin potential responses (SPRs). Successfully recorded in animal exploration of central mechanisms of EDA (e.g. Sequeira et al., 1995), SP recordings present several disadvantages linked to the acquisition requirements and skin sites properties (electrolytes, skin temperature, etc.). Consequently, despite their technical simplicity, SP recordings are rarely used in human studies, excepted when related with specific methodological purposes.

Figure 1.
Electrodermal recordings as skin conductance and skin potential techniques, taking origin in Féré's and Tarchanoff's approaches respectively. ***A****: Illustration of bipolar and unipolar skin sites, respectively for skin conductance (SC) and skin potential (SP) recordings; note also the typical electrodermal responses (uniphasic for SC and biphasic for SP).* ***B****: Broken and continuous arrows indicate standard skin placements of electrodes for SC and SP recordings, respectively. Iconographic adaptation from experimental apparatus of Kobayashi, Mandai and Sequeira at Ashikaga Institute of Technology (Japan, 2008).*



6. Electrodermal heritage: Looking to the future

Along the last century, EDA became a central physiological tool to explore most psychophysiological topics. Since 1980's, new approaches and disciplines reinforced its interest and enlarged its use in basic and clinical research.

Besides Féré's and Tarchanoff's contributions, the identification and applications of EDA are a typical result of interdisciplinary exchanges. In fact, in early days of EDA, three main influences can be considered: experimental rulers, initiated in German laboratories; clinical applications, emerging from French positions to deal with mental health and, finally, American psychologists looking for new methods of recording and analysis of electrodermal signals. These influences are also the expression of theoretical and technical information coming from physics, physiology, mental medicine, psychology and even spiritism (see Deren, 2011). More precisely, EDA became a privileged link between physiology and psychology interrogations, especially oriented to the comprehension of emotional behaviors (Boucsein, 2012). This corresponds to the need to explain emotional processes in normal individuals and the role of EDA as a potential indicator of emotional vulnerability in mental disorders (Miossec et al., 1986).

In more recent years, appeared new trends aiming to clarify the EDA's as a potential marker of cognitive and affective processes in different subfields of neuroscience. The first important point is related to the discovery of neural mechanisms subtending EDA central control. In this frame, animal research developed at the University of Lille represents a strong and significant input revealing main neural structures implicated in the excitatory and inhibitory command of electrodermal responses (Bloch, 1965; Roy et al., 1993; Sequeira et al., 1995). Secondly, many studies tried to establish the capacity of EDA to reveal the impact of arousal and valence dimensions of emotional stimuli; several researches confirm the fact that EDA is a robust index of emotional arousal (Lang et al., 1993; Sequeira et al., 2009; D'Hondt et al., 2010; Delannoy et al., 2015; Kosonogov et al., 2017) whereas it fails to discriminate negative from positive valence. Finally, other works used the EDA as a promising marker of cognitive or emotional processes related to decision making (Damasio et al., 1990), anticipatory and circadian behaviors (Amiez et al., 2003; Hot et al., 2005), subliminal stimulations (Silvert et al., 2004), reasoning (Carbonnel et al., 2006), cognitive loading (Salvia et al., 2012), psychosomatic interactions (D'Hondt et al., 2010), frontal lesions (Naveteur et al., 1993; Sanchez-Navarro et al., 2005), sleep processes and psychopathology (Delannoy et al., 2015; Martinez-Velazquez et al., 2017).

In conclusion, Féré and Tarchanoff, two discoverers with two different methodological and technical approaches, transmitted us a common scientific heritage, the EDA, still alive one hundred years later and promised to an expanding future in neuropsychology, psychopathology, neurology, chronobiology, criminology and in cognitive and affective neuroscience. Last but not least, Féré and Tarchanoff represented the early European ideal for the free transfer of knowledge between individuals, institutions and cultures.

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