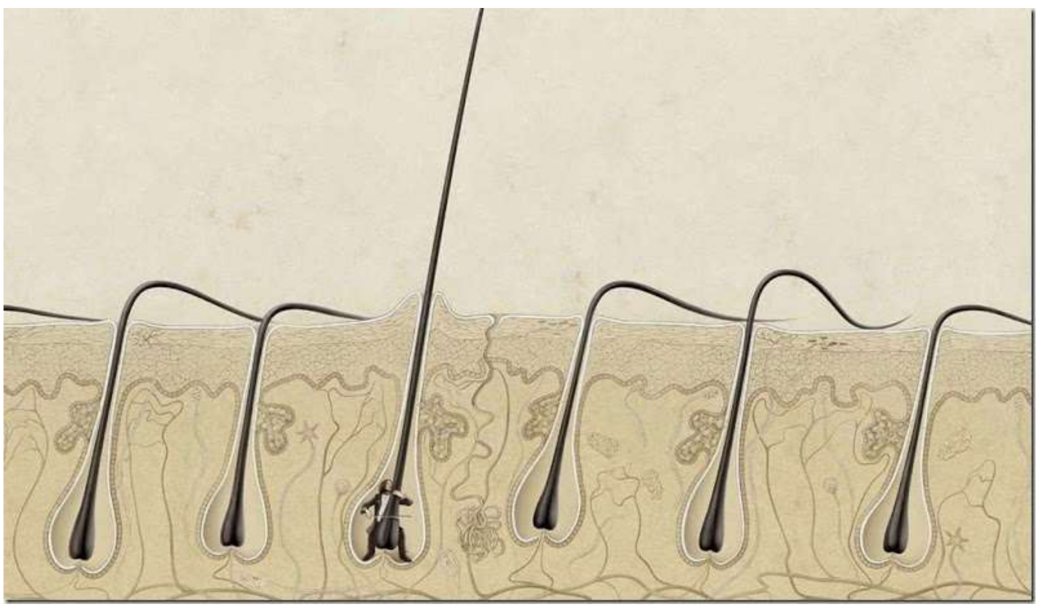
Goosebumps measurement

Psychophysiology and measures of pilo-erection in humans



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Report outline

This report synthesizes the current knowledge about the piloerection phenomenon in humans and the different methodologies developed to measure it. After a short introduction to the physiology of piloerection, different lines of measurement development are proposed. This report is written with one objective in mind: to provide the reader the key knowledge on piloerection that would provide a starting point to develop a reliable method for its measurement. We thus propose to incrementally enrich this report as a function of the questioning and discussions between the two parties. This strategy should allow a flexible and efficient way to focus the knowledge on the important points. The relevant existing literature is also provided (via separate files) to allow the reader to further explore the topic if needed.

Key concepts

- Goosebumps correspond to epidermis buckles created by contraction of multiunit smooth muscles arrector pili attached to the skin hair
- Piloerection is involved in themoregulation, emotional reactions and particular pathological states. Induction via individually adapted pieces of music is the most reliable way to induce goosebumps.
- Piloerecdtion have been reported to be maximal over forearms
- Piloerection is triggered by the sympathetic branch of the autonomic nervous system (α1-adrenergic receptors)
- Arrector pili contractions are graded and slow
- Goosebumps are already measured via detection of spatial frequency changes in the visual domain or mechanical distortion of the skin via deformation of spiral coplanar capacitors
- To date, the electromyographical response of arrector pili muscles during piloerection is not characterized
- The main challenge will be to isolate the specific response from the background noise (large movements, electrical activity of underlying skeletal muscles)
- Spatiotemporal decomposition of the electromyographical signal seems to be a key strategy to isolate piloerection signal from surrounding noise
- High density arrays of Ag/AgCl contact electrodes could be used in a first phase to maximize the likelihood of observing the signal

KEYWORDS for literature research: goose pimples OR goose flesh OR goose bumps OR shivering

Introduction to Goosebumps

For most mammals, piloerection (causing goose bumps, flesh or pimple) is a common method of modifying heat exchange. It is caused by the contraction of the arrecto pili muscles (AP), which are bodies of smooth muscle that extend from the fibrils of the dermis into connective tissue investment of the hair follicle. In many species, including familiar ones such as dogs, cats, and chimpanzees, raising the hair serves a secondary function of social warning of impending aggression. As humans possess relatively little hair and are often clothed, heat conservation through piloerection is usually regarded as insignificant and rudimentary. However, piloerection may become more important in conjunction with shivering, potentially enhancing the effectiveness of the shivering response. In human, piloerection is most often known as a reaction to cold and also to strong emotional stimuli.

Goosebumps are caused by arrector pili muscles contractions

The arrector pili muscle is a small band of smooth muscle that connects the hair follicle to the connective tissue of the basement membrane in non glaborous skin. In response to increased sympathetic nerve discharge, the arrector pili muscles at the base of tiny hairs in the skin contract and cause the hairs to become upright, trapping air and thus increasing the insulating layer of air around the body and minimizing heat loss. This is known as piloerection. As the muscle contracts, the epidermis buckles, creating "goosebumps" that are easily visible (Figure 1) and strongly elicited in forearms. The density of goosebumps at this location is around 16-18 hair follicles per cm^2 (Benedeck et al., 2010; Otberg et al., 2004) and a single goosebumps radius has been reported as around 2 mm (Kim et al., 2014). Note: it seems more plausible that this value corresponds to the diameter.

FIGURE 1GOOSEBUMPS IN HUMANS

Each hair follicle was once believed to be attached to a separate APM, but this has been refuted by more recent studies. Poblet et al. proposed that the APM associated with follicles in one follicular unit converge into one muscular unit and hence that all follicles within a unit share a single muscle. In a study conducted by Song et al., the structure of the APM was evaluated by three-dimensional reconstructions. The authors reported a variation in which two follicular units can share a single APM. They also suggested that only one muscular structure is involved in the follicular unit, which inserts tightly to the furthest follicle. Song et al. also reported that the APM forms a concave support for the sebaceous gland lobules. These lobules are located between the follicles and APM, forming an angular area.

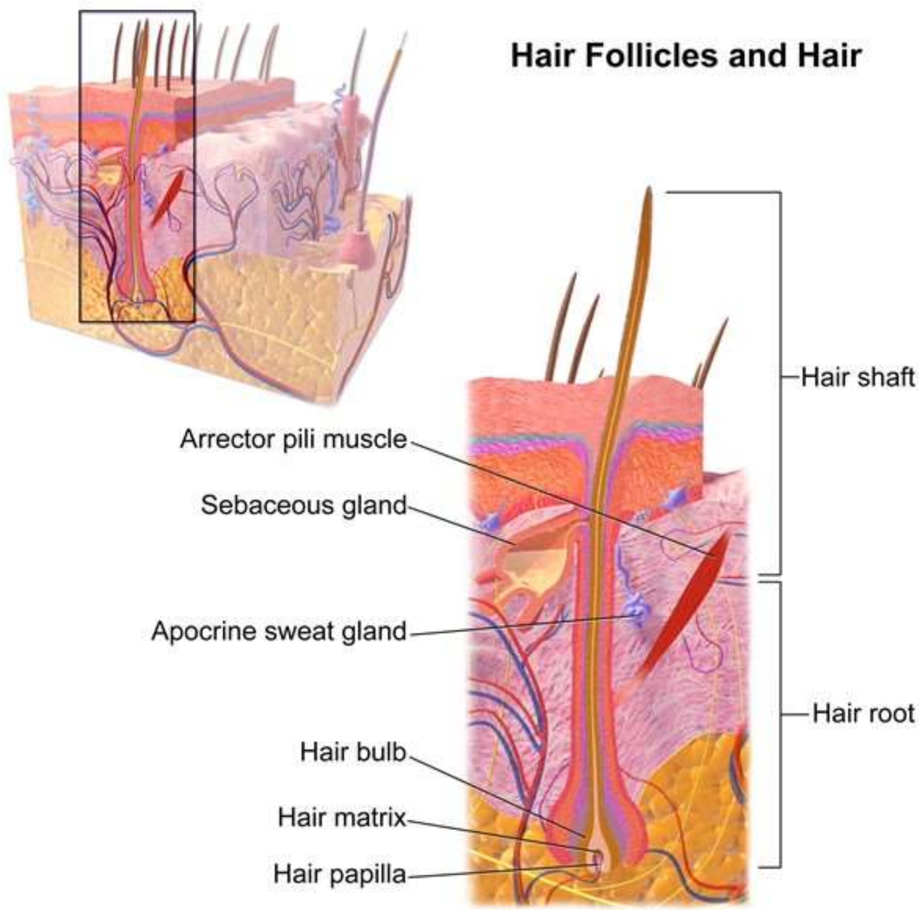

FIGURE 2 CROSS-SECTION OF ALL SKIN LAYERS

Arrector pili muscles are multiunit smooth muscles

Smooth muscles are composed of small, tapered cells with single nuclei, Smooth muscle cells do not have T tubules and have only loosely organized sarcoplasmic reticula. The calcium required for contraction comes from outside the cell and binds to a protein called calmodulin, rather than to troponin (as for skeletal muscles) to trigger a contraction event. The lack of striations in smooth muscles fibers results from the fact that the thick and thin myofilaments are arranged quite differently than in skeletal of cardiac muscles fibers. Because the myofilaments are not organized into sarcomeres, they have more freedom of movements and as a result can contract a smooth muscle fiber to shorter lengths than in skeletal and cardiac muscle.

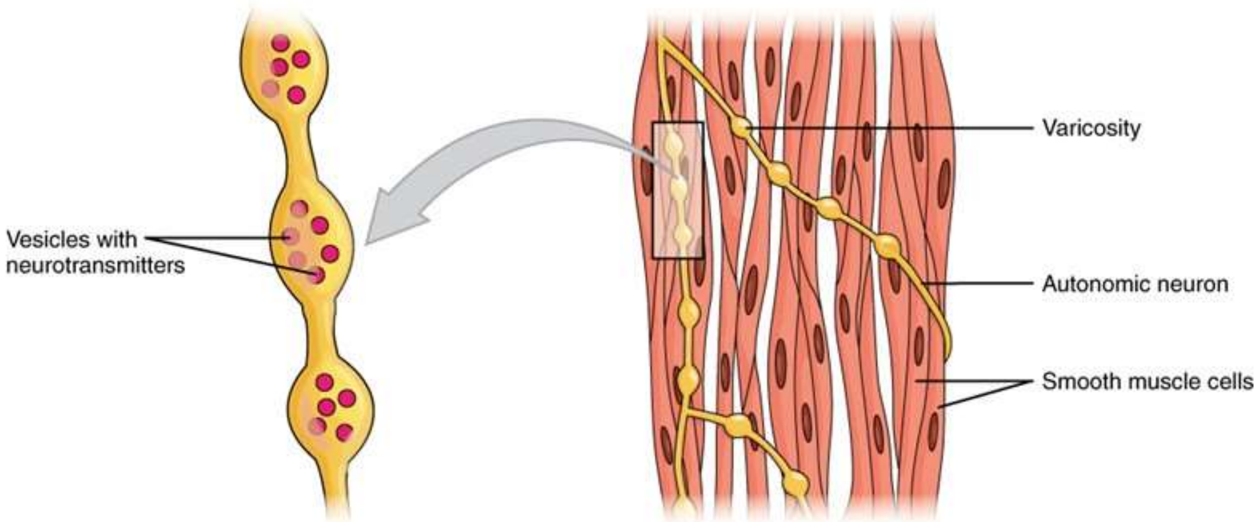

FIGURE 3 A SERIES OF AXON-LIKE SWELLING, CALLED VARICOSITIES OR "BOUTONS," FROM AUTONOMIC NEURONS FORM MOTOR UNITS THROUGH THE SMOOTH MUSCLE

Artrector pili muscles are multiunit smooth muscles, meaning that they do not act as a single unit (as single-unit visceral muscles) but instead is composed of many independent single-cell units. Each independent fiber does not usually generate its own impulse but rather responds only to nervous input (i.e., neurogenic activation). This type of smooth muscles are often found in bundles like in the case of the APM. The main consequence of APM physiological properties is that its contraction is graded, meaning that it is theoretically plausible to measure variations in contraction intensity. Of particular importance are the high metabolic economy of smooth muscle, which allows it to remain contracted for long periods with little energy consumption, and the small size of its cells, which allows precise control of very small structures, such as blood vessels. The contraction of smooth muscle is much slower than that of skeletal or cardiac muscle, it can maintain contraction far longer and relaxes much more slowly. The source of these differences lies in the chemistry of the interaction between the different proteins that composed smooth muscles fibers.

Piloerection can be evoked centrally and peripherally

APM are present throughout hairy skin and are activated centrally by cold exposure, fever, and strong emotions. In the periphery, piloerection is evoked directly by mechanical, thermal, electrical, or pharmacological stimuli or, as previously reported, indirectly via an axon reflex. Piloerection is generally not under voluntary control. It is used as an index of autonomic sympathetic activity and is thought to be mediated by α1-adrenergic receptors.

Piloerection, sebaceous and sweat secretions

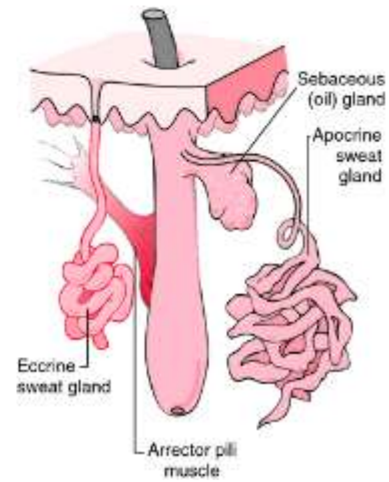

Figure 4: Sebaceous, eccrine and apocrine glands in relation to follicle hair

The skin of most mammals is characterized by the presence of sebaceous glands (see Figure 4), which produce lipid-containing sebum. Sebum contributes to the large majority of skin surface lipids, which are crucial for hair growth, moisturization of skin and hair, and the prevention of water evaporation from the skin surface. Recent research has suggested that sebum may also contain antioxidants, antimicrobial lipids, and pheromones. In humans, sebum excreted by the sebaceous glands is primarily composed of triacylglycerides, wax esters, and squalene (Zhang et al., 2014). To date, there is no reported evidence of a direct relationship between goosebumps elicitation and sebaceous secretions.

Sweat is emitted via two types of glands: apocrine and eccrine glands.

Apocrine glands are anatomically linked to the hair follicle (Figure 4), the sweat being secreted in the pilary canal of the hair follicle. Apocrine sweat glands are found in the armpit, around the nipples, between the anus and genitals, in the ear, and in the eyelids. They become active after the puberty, contain complex chemical compounds (sometimes related to pheromone-like effects) whose degradation by the skin bacteria produce the sweat odour. With regards to their distribution, the relation between piloerection and apocrine glands is unlikely to be functionally informative.

Eccrine glands are more broadly distributed and can be found at places where piloerection has been reliably measured (foreharm). Those glands are responsible of the electrodermal response. Interestingly enough, piloerection in emotional situations is often concomitant to electrodermal responses elicitation (a very well known autonomic measure of sympathetic activity). However, every electrodermal response is not accompanied with piloerection, showing the putative functional decoupling of those two autonomic responses. Moreover, eccrine sweat glands are anatomically distinct from hair follicles.

Induction of Goosebumps

Cold

Whereas it is well known that, in humans, piloerection is triggered by cold as a part of a reminiscent thermoregulation process of mammals, the induction of goosebumps via cold application as received little interest. In one recent study (Kim et al., 2014) the piloerection was induced by requesting one and only one participant to grab ice cubes in order to apply a sudden cold shock. It is thus difficult to evaluate the potential of this induction technic to induce goosebumps reliably. Hellman (1963) and Sakurai (1979) have demonstrated that pilomotor contractions (*in vitro* preparations) triggered by adrenergic or nicotinic substances are potentiated as the temperature decrease. It is thus worth considering performing goosebumps induction in fresh atmosphere to potentiate any other induction method.

Voluntary elicitation

Piloerection is a mechanism that is outside the control of will. However there are reports presenting individuals that are able to voluntarily induce piloerection (Lindlsey and Sassaman 1938; Benedeck et al., 2010). This situation is ideal since is it possible to reproduce the phenomenon is order to test for the reliability of the method detection. However, finding individuals with such ability is not common.

Emotion

The most reported induction method in humans is via emotion induction and particularly using music (Benedeck and Kaernbach, 2011; Craig, 2005; Grewe et al., 2006, 2007, 2009). Indeed, music is particularly prone to elicit chills and goosebumps in many individuals and in a reproducible manner. A very efficient strategy is first to select participants that know being prone to goosebumps during music listening and to request them to mention which particular piece of music evoke such a response. This individual strategy is currently by far the most efficient way to elicit piloerection in a control manner and should be tested as a method of reference.

Note: Upon acceptance of this report by the different parties, a study that proposes to test the power of music to elicit goosebumps will be submit to the ethical committee of the University of Geneva for acceptance. It should be discussed whether this study should be performed before a potential sensor has been made test the reliability of the induction method alone or to wait for the availability of a sensor prototype.

Chemical induction

In order to establish a reliable test that assesses cutaneous autonomic functions, Siepmann and colleagues (2012) have used iontophoresis of phenylephrine hydrochloride to trigger axon reflex-mediated piloerection. This technic also called electromotive drug administration (EMDA) delivers a medicine or other chemical through the skin (ions flow diffusively through the skin driven by an applied electric field). This induction technic is very efficient but require a specific medical protocol and should be considered as an alternative option if other less invasive induction methods are inefficient.

Faradism

Electrostimulation of the skin via a strong faradic current has been reported in one study (Lewis and Marvin, 1927). As reported by the authors: "*A coil is connected to a 2 volt accumulator, and the current from the secondary coil carried to twin platinum contacts (lying 11 mm. apart). The secondary coil is placed at such a distance that, when the current is led into the unmoistened skin it is quite painful, in fact almost intolerable.*" P.89 The method is said to elicit strong piloerections but the fact that this stimulation is painful prohibits its use.

Epilepsy

Piloerections have been described in patients suffering from temporal epilepsy during seizure (e.g., Rocamora et al., 2014). It would be theoretically possible to perform sensors test on this population or to use the sensor after its development as a diagnostic tool.

Other inductions

Goosebumps are sometimes described in reaction to a caress or to hearing nails scratch on a chalkboard.

Physical dimensions affected by piloerection

- Change in visible aspects of the skin (detection of topological changes of the skin)
- Mechanical deformation of the skin (detection of topological changes of the skin)
- Change in local electrical potential of the skin (detection of arrector pili electrical activity)

Existing methods for goosebumps recordings

Spatial frequency changes in the visible domain

Using visible topological changes to objectively measure piloerection is a methodology that was developed at the Institut für Psychologie of Kiel in Germany and published in 2010 (Benedek et al., 2010). The basic idea is that piloerection modifies the visible aspects of the skin, causing bumps and increasing the quantity of visible details. In sum, as goosebumps arise, spatial frequencies in the visible domain change. The authors, also experts in deconvolution technics applied to extract skin conductance responses, presented an optical recording device (Figure 4I) that records a portion of the skin (recording and illuminating parameters are reported p.990 of their article). The obtained videos are cropped, filtered and a discrete Fourrier transform is applied to quantify changes in spatial frequency power that are due to visible piloerection (Figure 4II). The authors also provide a complete Matlab toolbox to perform the frequency decomposition of the pictures/video (www.goosecam.de).

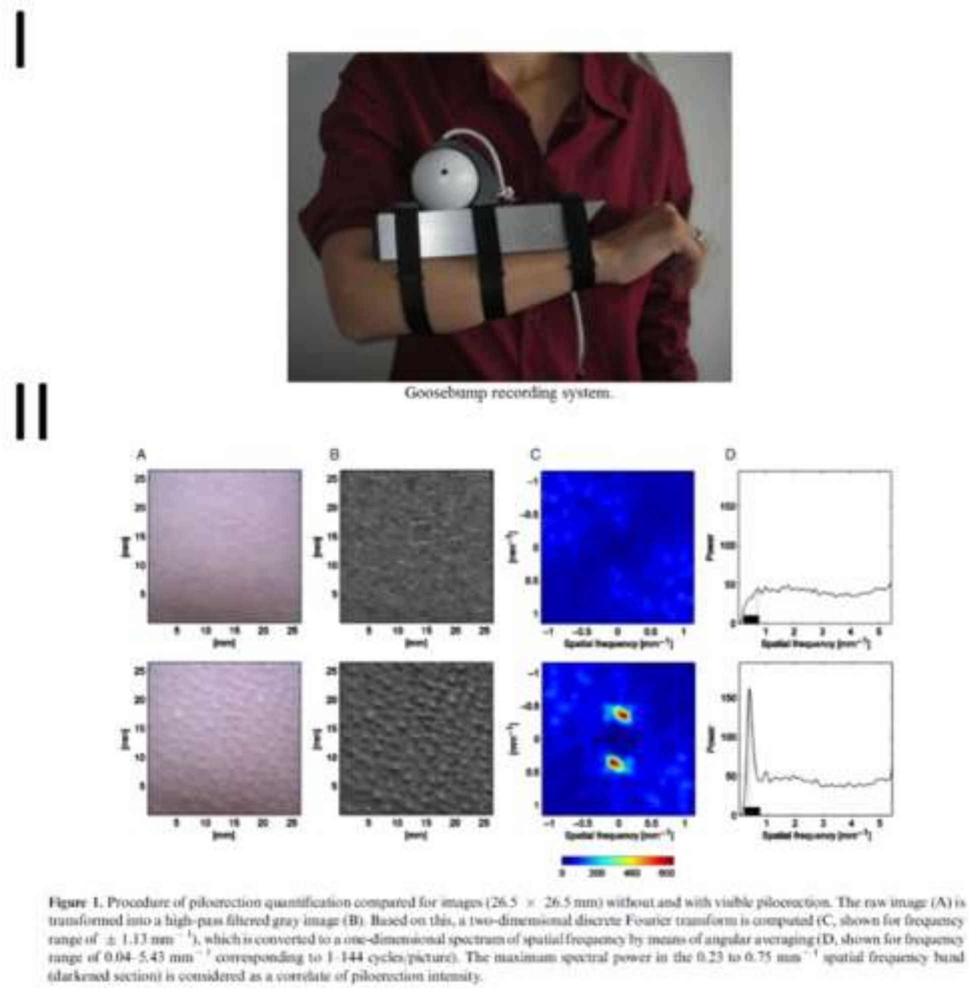

FIGURE 5: (I) PICTURE OF THE RECORDING SYSTEM. (II) PROCEDURE FOR PILOERECTION QUANTIFICATION (TAKEN FROM BENEDEK ET AL., 2010)

Although this methodology presents many advantages, it requires an emitting device and a sensor, stable illumination conditions, a fix distance from the sensor (camera) and the goosebumps (otherwise changes in spatial frequencies of interest are to be expected). Any potential emitting device and sensor should be firmly maintained on the skin in order not to move. Moreover, this methodology can't track any piloerection that would not be visible, for instance in cases in which APM contractions would be present but not strong enough to erect the hair.

Mechanical deformation of the skin through capacitors

Visible changes of the skins are caused by mechanical changes of skin's tissues. Measuring these mechanical changes is the objective of the methodology developed recently in the Department of Bio and Brain Engineering in Daejeon, South Korea (Kim et al., 2014). The basic idea is to use the mechanical deformation of the skin by piloerection to deform a capacitance, changing the ability of this latter to store an electrical charge. They designed 9 spiral coplanar capacitors (1.5 mm diameter) embedded as an array in a square made of rubber silicone of 2 by 2 cm size. Any produced goosebumps located beneath one of these capacitors is supposed to deform the sensor during piloerection. All technical details of the sensor and its sensitivity are reported in the article.

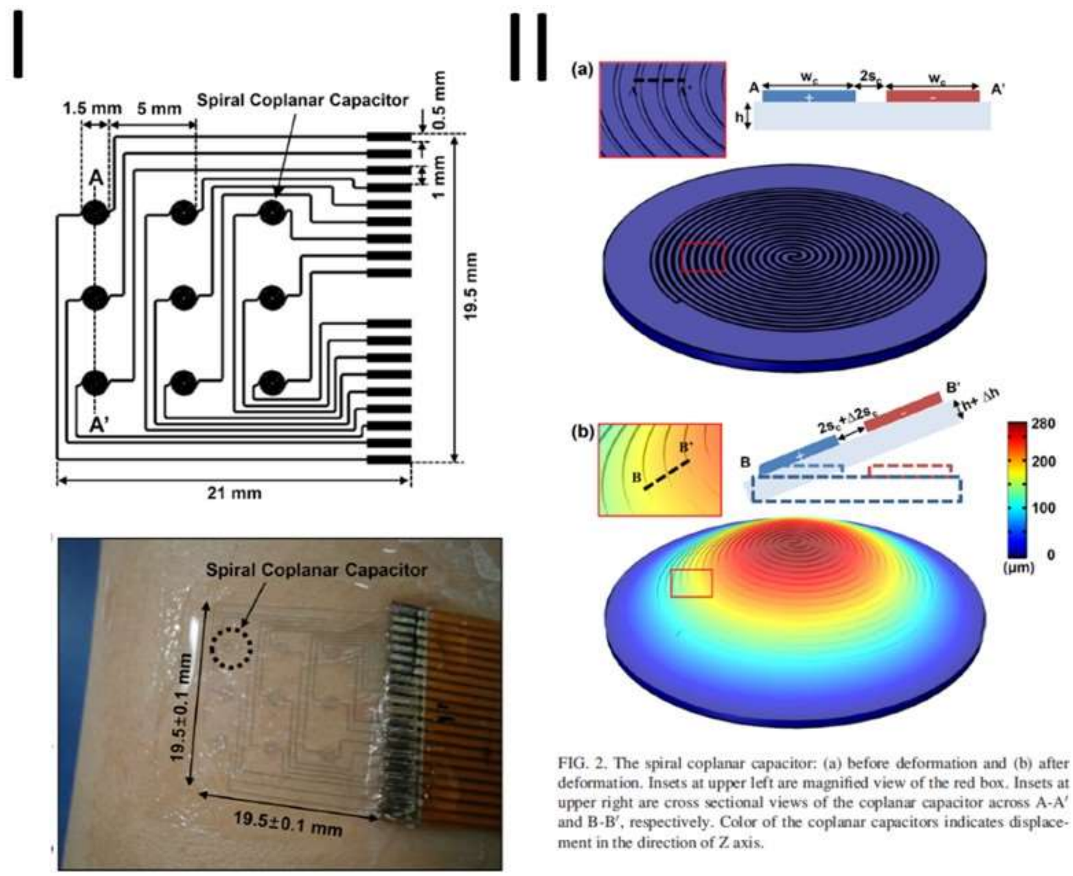

FIGURE 6: (I) UPPER PART, DIAGRAM OF THE SKIN PILOERECTION MONITORING SENSOR. LOWER PART, THE SKIN PILOERECTION MONITORING SENSOR CONFORMALLY ATTACHED TO THE DORSAL FOREARM. (II) THE SPIRAL COPLANAR CAPACITOR (TAKEN FROM KIM ET AL., 2014).

Being embedded in a rubber silicone directly stuck to the skin, this flexible array of sensors offers a very practical and stable positioning and is barely sensitive to humidity changes. Unfortunately there is no information concerning the sensitivity of this sensor to large deformation that could affect the whole array in case of body movements.

Towards electromyographical recordings of piloerection

Rationale of the measure

To our knowledge, direct measurement of APM activity has never been reported in humans. Recoding the electrical activity of these multi-unit smooth muscles constitute another potentially efficient solution to measure piloerection in a non invasive way. As already introduced in this report, piloerection is due to the contraction of multiunit smooth muscle triggered by neurogenic impulses from the sympathetic branch of the autonomic nervous system. Following the nerve's discharge, motor unit action potentials are generated at the muscle level and propagate along the fibers, causing the contraction of the multi-unit smooth muscle. This contraction is caused by electrical activity that can be recorded at the surface of the skin.

Surface electromyography

Surface electromyography (EMG) proposes to record the spatio-temporal summation of all muscular fiber potentials recruited at the skin level. These action potentials occur at random intervals. So at any one moment, the EMG signal may be either positive or negative voltage. Surface electromyography detects firings of aggregates of motor units that correlate well with the overall level of contraction of muscles underlying and near the electrodes. However, the poor selectivity of surface electrodes can make it difficult to pinpoint exactly which muscle/fiber is contracting. The amplitude of electromyograpical recordings of skeletal muscles can vary from fraction of microVolts to hundreds of microVolts, depending on the number of motor unit action potentials recruited, the size of the muscle and may different noise-related factors. Since arrector pili muscles are small muscles without many fibers, it can be expected that amplitude of APM contraction will be at the lower side of this interval, even less. Note that it is possible to record the electrical activity of muscles directly at the muscle level using invasive electrodes (i.e., needles). With regards to the objective of this project, invasive electrodes will not be considered.

High density EMG to improve signal to noise ratio

One of the main challenge to face in order to obtain small electrical signal from APM activity is the surrounding electrical noise coming from the underlying skeletal muscles as well as artifact that could emerged from body movements. High density EMG could constitute in that sense a promising way of increasing the signal to noise ratio by using the spatial information given by every electrode location. The basic principle is to reduce electrode size and dispose a great number of electrodes in an array in order to cover locations of the skin underneath which hair follicle will be present as well as where they will not be. By comparing the activity of both types of electrodes, there should be a way to extract the electrical information specific to the electrodes located above APM muscles.

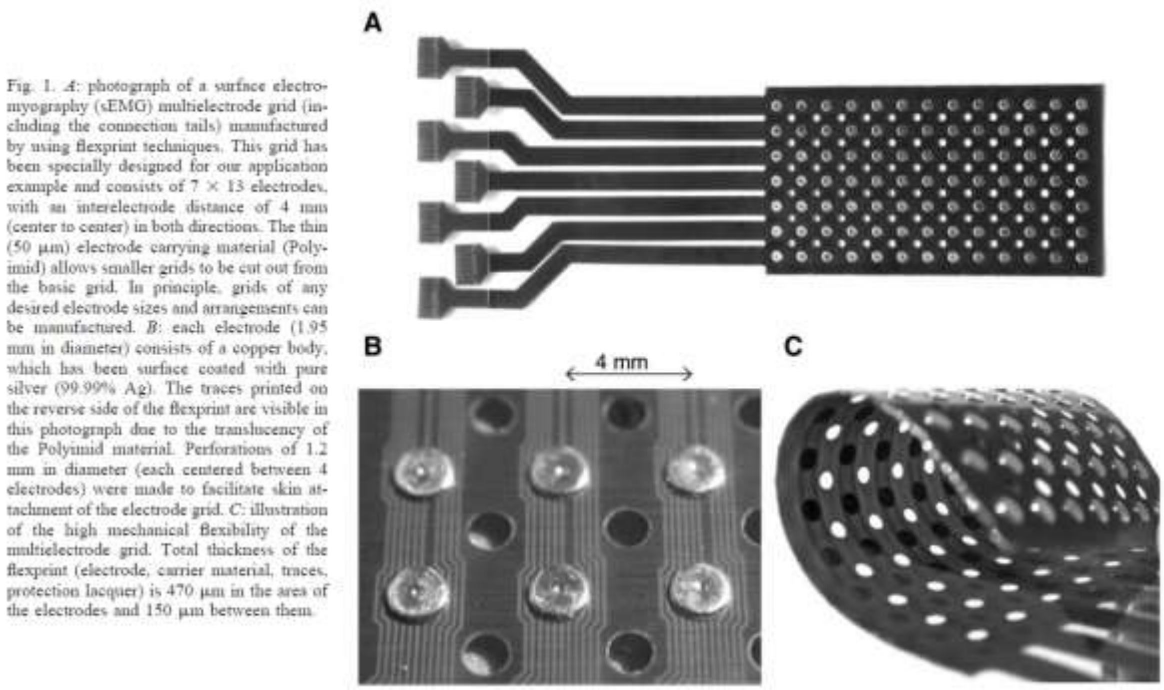

FIGURE 7 PHOTOGRAPH OF SURFACE ELECTROMYOGRAPHY MULTIELECTRODE GRID ALLOWING HIGH DENSITY EMG RECORDINGS (TAKEN FROM LAPATKI ET AL., 2004)

The presented sensor was designed with the aim of extracting single motor action unit potentials from the EMG, using the temporal and spatial information. Our objective is different but the basic principle and the analysis pipeline are quite similar.

Each electrode can be used to create different kind of montage: From classical bipolar montage (difference of potentials between two electrodes) to Laplacian montage (difference of potentials between one electrode and the averaged potentials of surrounding electrodes). With Laplacian montages it is theoretically possible to isolate the activity of APM muscles if they are located just beneath one (and only one) electrode because they should not/less affect the potential recoded on the surrounding electrodes. It is also possible to perform averaged-reference montage (difference of potentials between one electrode and the averaged potential of all the grid). With this latter, the activity common to all electrodes is subtracted, leading to a reduction of the electrical noise common to all electrodes (e.g., electrical activity of skeletal muscles, movements).