Psychophysiology, 47 (2010), 989–993. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2010.01003.x

BRIEF REPORT

Objective and continuous measurement of piloerection

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Abstract

Increasing attention is drawn to the investigation of piloerection (or goose bumps) in response to strong emotional experiences. This research is complicated by the need to rely on self-report measures. This article proposes an efficient method for the objective and continuous measurement of piloerection. It is based on an optical recording device combined with a discrete Fourier transform analysis quantifying the frequency power related to visible piloerection. The validity of the method was demonstrated in a proof-of-principle experiment involving a person with the exceptional ability to control the erection of his hair. The method reliably mapped all occurrences of visible piloerection and provided insight into the temporal dynamics of the underlying physiological process. It thus proved suitable for future experimental investigation of human piloerection.

Descriptors: Piloerection, Goose bumps, Chills, Discrete Fourier transform

Piloerection (also referred to as horripilation, pilomotor reflex, or goose bumps) denotes the visible erection of body hair in humans or animals. This action is achieved by the musculi arrectores pilorum, which are attached at one end to the hair follicles and at the other to the inner surface of the basal layer of the epidermis. Because neither of these attachments is to rigid structures, a contraction produces a twofold effect: The hairs stand up and the epidermis buckles so that 'goose bumps' appear (Hellman, 1963). The piloerector muscles are activated by the sympathetic nervous system. Although this is naturally an autonomous reaction, there is at least one report of a person who was able to voluntarily evoke piloerection (Lindsley & Sassaman, 1938). Piloerection is known as a reaction to cold but also to strong emotional experiences (Jänig, 2006).

For the last three decades, increasing attention has been drawn to piloerection and the sensation of chills (i.e., thrills or shivers down the spine) as indicators of intense pleasurable experiences especially in response to music (e.g., Blood & Zatorre, 2001; Craig, 2005; Goldstein, 1980; Grewe, Nagel, Kopiez, & Altenmüller, 2007; Panksepp, 1995; Sloboda, 1991; Zatorre, 2005). In the majority of these experiments, participants listened to pieces of music and were asked to continuously report on their experience of piloerection (or chills) by pressing a button or by giving a hand signal. However, the usage of self-report entails, at least, two methodological issues. First of all, it does not allow for the degree of objectivity commonly given for physiological measures. Secondly, it requires the participants to monitor their bodily sensations, which may draw off attention from the experimental stimuli. This is why researches have claimed that "[f]uture work must seek to use more objective measures to analyze this phenomenon" (Panksepp, 1995, p. 192).

So far, only two studies are known in literature employing more objective methods. In the single-case study by Lindsley and Sassaman (1938), a motion picture recording from the skin was analyzed offline. For single frames, the erection of hair was quantified by measuring the distance of the tip of any hair from the surface of the skin. In a study by Craig (2005), participants were asked to place their arm through a hole in a curtain while listening to music stimuli. An experimenter sitting on the opposite side of the curtain observed the arm and noted the occurrence of visible piloerection at 2- to 3-s intervals. Although these approaches represent valuable efforts allowing for increased objectivity, they are time-consuming and may not fully resolve the aforementioned issues, as human judges are still required. The aim of this article is to propose an efficient method for the objective and continuous measurement of piloerection, which is based upon an optical recording device combined with an automated analysis of spatial frequency.

Methods

Participant

A 35-year-old right-handed male served as the participant. He was recruited in the course of a campaign looking for people with the ability to voluntarily evoke piloerection. In an informal interview, the participant explained that the elicitation is brought

The authors are grateful to the scientific workshop of the Department of Experimental Physics of the University of Graz, Austria for the assistance in the construction of the recording device.

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about by flexing his facial muscles and focusing on a location in his neck from which a shiver and, eventually, piloerection spread down his spine and into his arms. Eight years ago, he realized that he was able to provoke piloerection while being exposed to the vibrations of an electrical hair clipper. This experience fascinated him and motivated further training of this ability. He agreed to participate in an experimental session and gave written informed consent.

Apparatus

An optical recording device was constructed in order to enable video recordings from the skin surface under standardized conditions. The central body of this device is a hollow aluminum bar (160 × 40 × 40 mm) which can be placed lengthwise on a limb (e.g., the forearm) and attached firmly by means of three elastic straps. On one side of the bar, a customary webcam (QuickCam Express; Logitech, Morges, Switzerland) is fixated in an adequate cut-out. It points vertically towards a second cut-out (30 × 50 mm) on the opposite side of the bar, which opens to the skin below the device. The camera lens holds a stable position 46 mm above the skin surface and captures a skin area of 26.5 × 32.4 mm. The camera records 24 Bit color images at a resolution of 288 × 352 pixels—one millimeter of the skin thus corresponds to 10.9 pixels. Inside the recording device, three white LEDs are placed at a height of 20 mm and a distance of 50 mm from the cut-out, thus illuminating the skin from an average angle of 15°. The acute angle of the light incidence causes unilateral illumination of any elevation of the skin (such as goose bumps). An additional green LED serves as a marker signal. It is positioned in a way that a green spot will be visible in one corner of the recorded images as soon as the marker light is turned on. The recording device is connected to a PC via USB. The USB connection manages data transfer but also provides power supply for the camera and the white LEDs. The marker LED obtains power from a 16 Bit digital I/O device (RedLab 1208LS; Meilhaus Electronic, Puchheim, Germany), which is controlled by Matlab (The Mathworks, Natick, MA) via a USB connection. The video acquisition was carried out by the video capturing software VirtualDub 1.7.7 (available at www.virtualdub.org) using a sampling rate of 10 frames per second. The recording device was constructed using commercially available components costing less than 40 Euro in total; however, technical assistance may be required to ensure stabile fixation of all components.

Quantification of Piloerection Intensity

The intensity of piloerection was quantified frame by frame for the entire recorded video. A single video frame corresponded to a 288 × 352 pixel color image (see Figure 1A). Initial preprocessing involved the selection of a maximal quadratic image section (i.e., 288 × 288 pixel capturing 26.5 × 26.5 mm or 7.02 cm^2), conversion to gray scale, and application of a high-pass filter (cut-off at 4 cycles/picture) in order to correct for trends in illumination strength due to the natural curvature of the skin (see Figure 1B). Based on the preprocessed image, a two-dimensional discrete Fourier transform (DFT) was computed. The DFT result was corrected for the $1/f^2$ characteristics of natural images (Field, 1987) and arranged so that the zero-frequency component was located at the centre of the two-dimensional frequency spectrum (see Figure 1C). As directional information of frequency components were of no interest, angular averaging was performed resulting in a one-dimensional spectrum of radial frequency power (see Figure 1D). Finally, the intensity of piloerection was quantified as the maximum amplitude within a restricted frequency range of 0.23 to 0.75 mm^{-1} (i.e., 6 to 20 cycles/picture). This range appeared plausible, since the density of hair follicles in the forearm averages 18/cm^2 (Otberg, Richter, Schaefer, Blume-Peytavi, Sterry, & Lademann, 2004), from

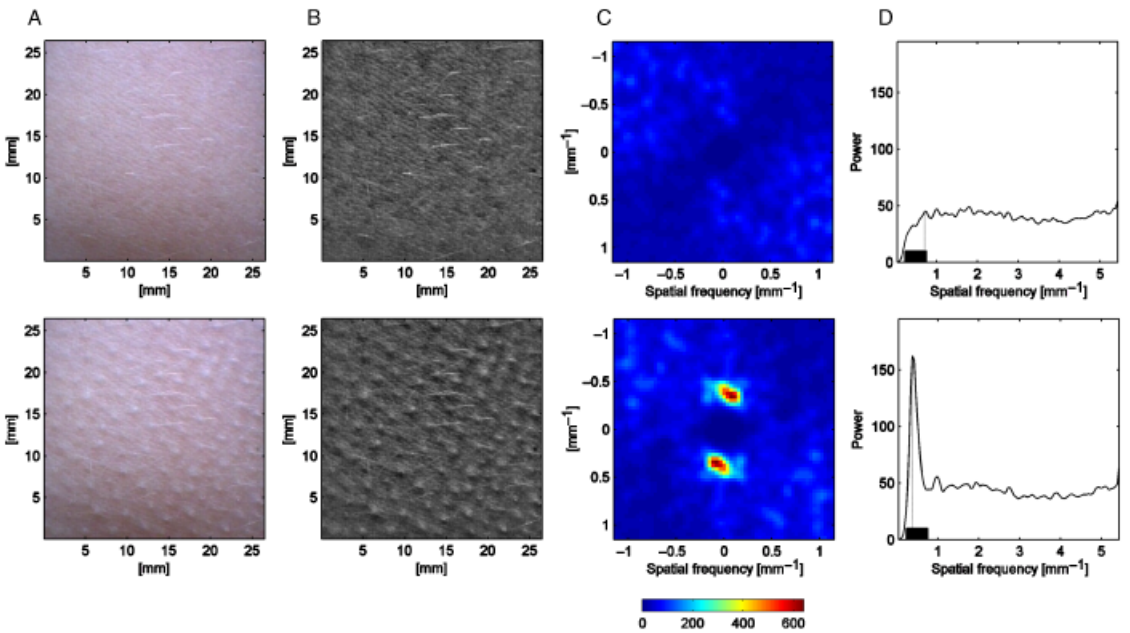

Figure 1. Procedure of piloerection quantification compared for images (26.5 × 26.5 mm) without and with visible piloerection. The raw image (A) is transformed into a high-pass filtered gray image (B). Based on this, a two-dimensional discrete Fourier transform is computed (C, shown for frequency range of ± 1.13 mm^{-1}), which is converted to a one-dimensional spectrum of spatial frequency by means of angular averaging (D, shown for frequency range of 0.04–5.43 mm^{-1} corresponding to 1–144 cycles/picture). The maximum spectral power in the 0.23 to 0.75 mm^{-1} spatial frequency band (darkened section) is considered as a correlate of piloerection intensity.

which a one-dimensional frequency of 0.42/mm can roughly be derived assuming equal distribution.

All steps of the analysis were performed by means of self-developed Matlab routines compiled in analysis software called Gooselab. The software and additional information and pictures of the software and the recording device are available at www.goosecam.de or via the Software Repository of the Society of Psychophysiological Research (www.sprweb.org).

Experimental Task and Procedure

A solid rectangle of changing color was presented over a white background. When the rectangle was black, the participant should just sit and relax (rest condition); when it was blue, the participant should engage in evoking piloerection (activation condition). Both conditions lasted for 30 s and alternated continuously. The session started with a rest condition which was followed by ten pairs of activation and rest conditions.

The experiment took place in a soundproof cabin. The participant was seated in a comfortable chair with his arms placed on broad, flat arm rests. The optical recording device was attached to the left dorsal forearm, which was identified as one of the most common places to experience piloerection (Craig, 2005; Goldstein, 1980). The participant was told to find a comfortable seating position and to avoid any unnecessary movements during the experiment. The experimenter left the cabin and the stimuli were presented on a 20'' TFT screen, which was located 2 feet in front of the head of the participant. The experiment took about 30 min.

Statistical Analysis

Based on the piloerection intensity data, onset and offset latencies of piloerection were evaluated relative to the onset time of activation and rest phases. The baseline was defined as the average amplitude in the first rest condition (300 frames). Onset of piloerection was identified at the time when the measure exceeded a certain threshold, which was defined as the baseline plus 10% of the response range (i.e., total maximum amplitude minus baseline); the offset was identified at the time when the measure went below the threshold.

For univariate repeated-measures ANOVA, degrees of freedom were corrected by means of the Greenhouse-Geisser method where appropriate, and Bonferroni post-hoc tests were used for pair-wise comparison of means.

Results

Visual inspection of the recorded video by four independent judges indicated that the participant was able to voluntarily evoke and stop piloerection, following the predefined schedule, ten consecutive times. The dominant spatial frequency for frames within the activation phases was 0.40 mm^{-1} ($SD = 0.06$).

Figure 2 shows the course of the measure of piloerection for the experimental session (solid line). Before the first activation phase, the measure reflects a stable baseline ($M = 44.01$; $SD = 1.06$). In the activation phases, the measure shows a steep initial rise, which soon flattens but will continue to rise until the end of the activation phase for most trials. As an activation phase ends and a rest phase begins, the measure initially shows a steep decline, which soon passes into a slow approach towards the baseline level. In the activation phases, the maximal level attained ranged from 127.90 to 169.96 ($M = 150.55$, $SD = 12.90$).

The course of rise and decline appears to resemble an exponential approach towards a maximum level or towards the baseline, respectively. If this was the case, deconvolution of the intensity measure with an appropriate exponential function should result in a driver function with approximately vertical gradients for incline and decline (more details on the employment of deconvolution on physiological data can be found in Benedek & Kaernbach, in press). As shown in Figure 2 (dotted line), the driver function resulting from deconvolution with an exponential function (a time constant of 0.4 s was the maximum that did not give oscillations) shows nearly instantaneous declines of piloerection activity. The time course of the rise in piloerection is, however, not significantly rectified by this deconvolution.

The onset and offset latencies of piloerection, based on the intensity measure and the derived driver signal, were compared with the evaluations of four independent judges, who reported observable onset or offset of piloerection in the course of a thorough frame-by-frame inspection of the recorded video.

Piloerection onset was judged to occur 5.15 s ($SD = 1.17$) after onset of the activation condition, and offset was judged to occur 10.80 s ($SD = 1.98$) after onset of the rest condition. The estimated onset latency was significantly shorter for evaluations based on the intensity measure ($M = 2.32$, $SD = 0.95$) or the driver signal ($M = 1.09$, $SD = 0.69$; $F[2,18] = 62.11$, $p < .001$, $\varepsilon = .52$, $\eta^2 = .87$). Piloerection offset latency based on the intensity measure did not differ from visible inspection ($M = 10.3$, $SD = 2.11$), but was markedly shorter if identification was based on the driver signal ($M = 3.35$, $SD = 0.79$; $F[2,18] = 79.66$, $p < .001$, $\varepsilon = .85$, $\eta^2 = .90$).

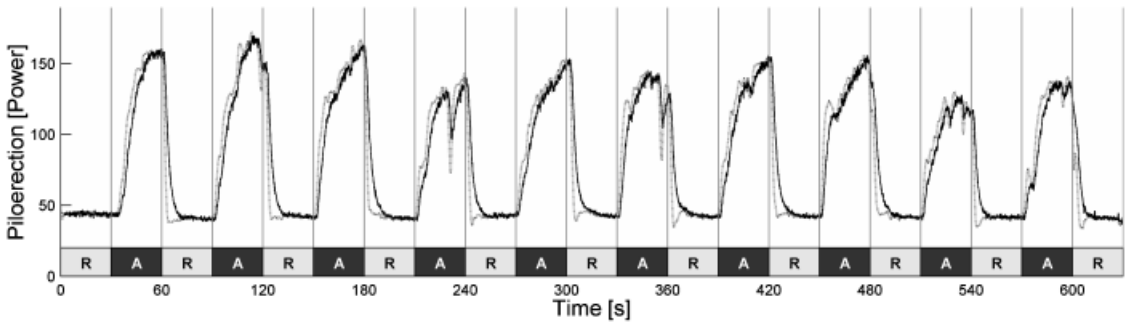

Figure 2. The course of piloerection (quantified by means of the dominant spatial frequency power; solid line) and the derived driver (after deconvolution with an adequate exponential function; dotted line) displayed for the whole experimental session including eleven rest phases (R) and ten activation phases (A) of 30 s each.

Discussion

A method for the objective and continuous measurement of human piloerection was validated in a single-case experiment involving a male with voluntary control of his pilomotor muscles. The participant succeeded in evoking visible piloerection in ten consecutive trials, which was reliably mapped by the DFT-based analysis of the video recording of the skin surface of the forearm.

The analysis of images displaying piloerection yielded a dominant frequency of 0.40 mm^{-1}. Assuming virtually equal distribution of hair follicles over the skin of the forearm, this conforms to a density of about 16 hair follicles per cm^2, which is in line with the density of 18/cm^2 reported by Otberg et al. (2004).

The measure of piloerection showed stable nonzero baseline intensity. A stable baseline should generally be easy to obtain, since piloerection usually does not occur in the absence of specific stimulation. In the case of anesthetized cats, the pilomotor neurons supplying the tail were found to be silent under thermoneutral conditions (Grosse & Jänig, 1976). In the course of further data processing, one could thus consider subtracting the initial baseline value from the data in order to establish a zero baseline.

The participant was able to evoke piloerection within less than 3 s. Piloerection intensity then showed a steep initial rise, which soon flattened but continued for the whole activation phase (i.e., 30 s) in most cases. We assumed that the biomechanical processes underlying hair erection (and lying down) may be described by an exponential time course. Deconvolution of the data, using an adequate exponential function, revealed that the driver function that underlies piloerection shows a gradual rise, but a virtually instantaneous decline. This indicates that the cessation of piloerection is indeed driven by biomechanical processes with an exponential time course, whereas the persistent increase of piloerection over time reflects a gradual increase of activation.

Human judges confirmed that the DFT measure is indeed due to visible piloerection. However, they appeared to be less sensitive in the detection of piloerection onset or offset than the threshold-analysis based upon objective measures. The low sensitivity of human judges may be ascribed to change blindness (e.g., Simons & Rensink, 2005), a common effect for tasks involving the detection of minute visual changes over time. The seemingly late reaction (of all measures) to the offset instruction is due to the threshold criterion: Whereas only little activation of piloerection is needed to pass the threshold on onset, most of the activation must have been gone before the activation measure falls below the threshold at offset. The identified onset and offset latencies of the driver most closely matched the times predefined by the schedule of the experiment (1 and 3 s after respective condition onset). This suggests that the driver represents the physiological activation of pilomotor neurons underlying visible piloerection. The use of this measure would be especially beneficial for the precise identification of onset and offset of pilomotor activity.

Some limitations of this proof-of-concept study should be discussed. First and foremost, the assessment of piloerection was performed only for one single subject and only at one single location of the skin, namely, the dorsal part of the forearm. This position is known as a common location for experiencing piloerection (Craig, 2005; Goldstein, 1980) and also proved appropriate in the present study. However, differences in hair density may be expected due to inter-individual differences and for the assessment at different locations. Otberg et al. (2004) reported comparable densities for forearm, thorax, thigh, and calf (18, 22, 17, and 14/cm^2), but densities up to twice as high for the back and the upper arm (29 and 32/cm^2). For a density twice as high, the dominant frequency would increase by the factor square root of 2 (i.e., from 0.40 to around 0.57 mm^{-1}). The frequency range used in the present study (i.e., 0.23 to 0.75 mm^{-1}) would be adequate for even higher differences in the dominant frequency and thus can be expected to manage typical variations in hair density. Differences in tone or other characteristics of the skin (e.g., ratio of terminal and vellus hair) may affect the absolute amplitude of the DFT but do not affect the dominant frequency. Again, these differences should not entail changes of the analysis parameters. The method thus is expected to be quite robust to typical variation of skin characteristics.

As another limitation, piloerection was studied as a voluntary but not as an emotional response. The investigation of voluntary piloerection allowed studying the basic response behavior under controlled conditions by means of predefined activation phases. Piloerection in response to emotional stimuli is assumed to obey the same physiological principles as for voluntary piloerection and thus to follow the same response constraints (e.g., onset latency). However, different emotional experiences are expected to result in more variation with respect to intensity and duration. This should be especially true since piloerection is elicited more effectively by dynamic stimuli (e.g., music pieces or tactile stimulation) rather than static ones (e.g., emotional pictures; Grewe, Katzur, Kopiez, & Altenmüller, in press).

The availability of an objective and continuous measure of piloerection allows for a more powerful investigation of this phenomenon. It provides the adequate means to study the relationship of visible piloerection to the experience of chills. Moreover, it facilitates the unbiased study of psychophysiological correlates of piloerection. One of the most promising avenues for future research is the study of the emotional quality of experiences and states accompanied by piloerection. The absence of spontaneous activity, and its unresponsiveness to small changes in basic arousal, suggest a certain specificity of this psychophysiological response. These investigations might, therefore, bear interesting implications for the ongoing debate on dimensional versus modular models of emotion.

In conclusion, a valid method for the objective and continuous measurement of piloerection in humans was presented. The measurement of piloerection thus advances to meet the methodological standards generally claimed for the empirical assessment of any psychophysiological measure. This should facilitate the study of emotional piloerection and, more generally, expand the scope of psychophysiological research.

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(Received August 3, 2009; Accepted October 23, 2009)