**Volitional control of piloerection: objective evidence and its potential utility in
neuroscience research**

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Abstract

The ability of volitional control of piloerection has been reported in a rare subset of individuals. This ability may be useful to study involuntary emotional piloerection, as research on this phenomenon has suffered from low reproducibility. However, objective evidence at a group-level and stability under experimental constraints remain to be examined. The present study aimed to validate existing findings of voluntary generated piloerection (VGP) and to examine its potential contribution to neuroscientific research based on objective evidence of this ability. In Study 1, to confirm the characteristics of VGP reported in previous studies and identify individuals with VGP capability, an online survey of VGP candidates found through a large-scale screening was conducted. In Study 2, a total of 18 VGP holders participated in a mail-based piloerection measurement experiment, and the nature of VGP was examined based on the objective evidence obtained by image-based analysis (GooseLab). The results of the web survey largely recapitulated the characteristics of VGP reported in previous studies, and objective measurements revealed the utility of this ability in neuroscientific research. For some participants, VGP appeared to be emotionally promoted, which suggests that VGP shares the emotional nature of involuntary piloerection. The findings from this study demonstrated the possible contribution of VGP to elucidating the mechanism of involuntary emotional piloerection and the neural basis of piloerection itself.

Keywords: piloerection, goose bumps, volitional control, autonomic, objective measurement, emotion

1 Introduction

Piloerection is an autonomic response observed during strong emotional experiences. Because of the variety of related emotions and preceding stimuli, it is challenging to dissect its mechanistic relationship with emotion. Addressing the neural basis of piloerection would be beneficial to advance our understanding of emotional piloerection, but the low occurrence of piloerection in experimental settings poses great difficulties for neuroscience research. In the present study, we focused on the volitional control of piloerection to overcome such difficulties and investigated its reproducibility.

Although various types of emotions may relate to piloerection, there is a lack of empirical research due to the difficulty of eliciting this phenomenon experimentally. Early studies of human emotional piloerection emphasized the role of fear and anger (Darwin, 1872). On the other hand, piloerection has been associated with aesthetic experiences (or “being moved”), triggered by Goldstein's work that positioned it as a component of chill (or thrill), a psychological concept related to strong emotional experiences (Goldstein, 1980). Recently, other emotional sources such as awe (Keltner and Haidt, 2003; Schurtz et al., 2012) and surprise (Maruskin et al., 2012) have also been suggested. The most promising stimuli for piloerection are artistic stimuli such as music, video, and poetry. However, even these stimuli only cause piloerection in approximately 40% of participants in the laboratory (Wassiliwizky et al., 2017), which is an impediment to experimental research.

The voluntary control of piloerection may solve the problem of reproducibility. The autonomic nervous system (ANS) functions largely outside of consciousness, but the abilities possessed by rare individuals or strategies learned through training such as biofeedback methods enable volitional control of ANS activities, including heart rate (Brener and Hothersall, 1966; Bell and Schwartz, 1975; Jones et al., 2015), blood pressure (Lowdon et al., 2011), electrodermal activity (Nagai et al., 2004; O’Connell et al., 2008), and pupillary response (Ekman et al., 2008). These

abilities or strategies have been used in neuroscience research to examine the centers of volitional ANS control itself (Jones et al., 2015) and specific autonomic activity subject to voluntary control (Nagai et al., 2004).

Previous studies have reported cases of individuals with the ability to volitionally control piloerection (Maxwell, 1902; Lindsley and Sassaman, 1938; Tsujiuchi et al., 2002; Benedek et al., 2010; Uchida et al., 2019). Benedek et al. objectively recorded piloerection caused at a constant pace, suggesting the potential of voluntary piloerection in neuroscientific research. A recent group study (Heathers et al., 2018) has investigated the overall nature of this ability, characterizing voluntarily generated piloerection (VGP) as produced by volition alone, without any imagination of emotional experiences or stimuli; most strongly formed on the head, neck, or arm; and easily performed by individuals with this ability with a short latency. In addition, VGP was used in situations where involuntary piloerection likely occurred, accompanied by some psychological state experienced during involuntary piloerection. If the group with VGP reported by Heathers et al. can reliably control piloerection as reported by Benedek et al., this may strongly contribute to experimental studies for several reasons. First, VGP will assist in elucidating the central control of piloerection. Modern understanding of the ANS has revealed the orchestrated involvement of cortical structures (Benarroch, 1993). According to this view, studies of pilomotor seizures that are common to temporal lobe epilepsy (Loddenkemper et al., 2004) and direct electrical stimulation of the human brain (Fish et al., 1993) suggest involvement of cortical areas, particularly in the temporal lobe area, in episodes of piloerection. VGP provides a non-invasive approach to validate these findings and to reveal the generator of piloerection whose exact location remains unidentified (Brody et al., 1960). More importantly, VGP provides a powerful methodology for laboratory research of emotional piloerection. The fact that VGP shares situations and psychological effects with involuntary piloerection suggests that VGP can be used as a research model to investigate the mechanisms underscoring emotional piloerection.

Considering the high reproducibility of VGP, a dramatic improvement in the observability of emotional piloerection can be expected.

Considering the potential contribution of VGP to neuroscience research of piloerection, the current study aimed to demonstrate its experimental reproducibility. As existing evidence on piloerection at the group-level was obtained via self-report, the physical occurrence of VGP should be objectively verified. It is also necessary to clarify whether VGP can be generated in the face of various constraints intrinsic to experimental procedures or experimental environments. For these purposes, we replicated the studies of Heathers et al. (2018) and Benedek et al. (2010) in combination. More specifically, we conducted an online survey of VGP-capable individuals to verify the nature of VGP and obtained additional information related to its execution under the constraints of the experimental environment (Study 1). Subsequently, objective and quantitative data on VGP was obtained by a mail-based self-execution experiment to evaluate the feasibility of VGP within the experimental procedures (Study 2).

2 Study 1

The purposes of Study 1 were to verify the nature of VGP reported by Heathers et al. (2018), obtain additional information on its suitability for experimental studies, and identify VGP-capable individuals for objective measurements in Study 2. For these purposes, a large-scale screening and web survey were conducted. The study was conducted according to the guidelines of the local ethics committee of Kwansei Gakuin University. Since the local ethics committee did not request any approval procedure if researchers conformed to committee guidelines, no specific approval procedure was conducted.

2.1 Methods

2.1.1 Participants

In the survey, 70 VGP candidates recruited through a screening procedure and three VGP holders

identified in advance attended the survey and received 1,500 yen for their participation. In the screening process, 4,061 respondents responded whether they could volitionally invoke piloerection without exposure to cold or emotional stimuli. Of the 112 individuals who indicated volitional control of piloerection, 70 individuals who could participate in the subsequent study attended the survey.

2.1.2 Materials

2.1.2.1 Questionnaire

A questionnaire on volitional piloerection was constructed using an online survey tool. The questionnaire largely reproduced those used by Heathers et al. (2018) and included some additional questions. The participants were asked about the outline of the ability (acquisition episodes, acquisition age, execution methods, and subjective difficulty), bodily reactions (body areas of piloerection and its control, latency and decay, accompanying physical reactions and sensations), contexts (activities in which they use this ability, its effects, enhancing involuntary piloerection by this ability, and situations promoting the ability), and physical conditions (the influence of body movement, eye condition, posture, and breathing). In addition, the participants were presented with a video clip that recorded the procedure for performing volitional piloerection and were asked the extent to which they could evoke piloerection according to instructions.

2.1.2.2 Experimental video

A video clip was created to present the procedure of the self-performed test for volitional piloerection. Replicating the procedure used by Benedek et al. (2010), both 30 seconds of rest and piloerection conditions were alternately repeated. The start and end cues for each condition were presented auditory, and the video included five piloerection trials.

2.1.3 Procedure

The screening procedure and recruitment of VGP candidates were conducted by a research company. The pre-specified VGP holders were directly asked to participate in the survey. The

participants accessed the online questionnaire in their own time and were informed about the detailed information of the survey. A total of 64 participants (61 VGP candidates and three VGP holders) who provided consent to participate responded to the following questionnaire.

2.2 Results

2.2.1 Identifying the VGP holders

First, participants were categorized based on how to generate piloerection extracted from the answers of execution methods and acquisition episodes. According to Heathers et al. (2018), VGP is as voluntary as volitional movement without any imagination of emotional experiences or stimuli. In this study, 25 participants (39%) were identified as VGP holders who mentioned direct volition to elicit piloerection or body-related effort. The other 22 participants (34%) responded to the recall of the antecedents of involuntary piloerection. Two participants (3%) referred to normal involuntary piloerection, and 15 participants (23%) did not provide a clear answer. In the following, we will describe the data obtained from VGP holders (Table 1).

2.2.2 The characteristics of VGP

VGP holders acquired this ability at 19.1 years old ($SD = 8.4$) on average. They execute VGP most commonly through "bodily focusing", followed by "recall of sensation during involuntary piloerection" and "direct volition". Most of them (68%) regarded this ability more or less easy to execute.

2.2.3 Physical response

Piloerection occurred on the arms in most respondents (96%), followed by legs (36%) and neck (16%). Arms were overwhelmingly reported as the most intense site (80%). As most respondents (80%) reported latencies within 5 seconds, piloerection occurred quickly, but its decay took longer. In most cases, sites and laterality of piloerection were uncontrollable (92% for both). The most common physical sensation accompanied by VGP was chills (84%). There were few reports of physical reactions associated with VGP, including tremors (20%) and muscle tension (16%).

2.2.4 Context of VGP

Some respondents (32%) reported using VGP to prolong involuntary piloerection, and a limited number of respondents provided examples of situations in which VGP was actively used, which included cold conditions (16%) and emotional experiences (8%). Responses on the effects of VGP were also limited, which depicted increases in body temperature (8%) and elimination of physical discomfort (8%). VGP appeared to be easy to execute in certain antecedent situations, including cold environments (28%) and emotional experiences (24%).

2.2.5 Physical conditions

The majority of respondents (60%) reported that they could perform VGP without any physical movement. Eye condition, posture, and breathing did not affect VGP; most respondents could execute this ability regardless of these physical conditions.

2.2.6 VGP execution test

While only five individuals (20%) were able to elicit piloerection in all five trials along the experimental video, 19 respondents (76%) were able to run VGP in more than half of the trials.

2.3 Discussion

The nature of VGP observed in this study largely reproduced that reported by Heathers et al. (2018), further demonstrating the existence of this ability. Consistent with the definition in the previous study, the ability enabling the generation of piloerection by attempting to elicit piloerection itself or to reproduce the physical experience of involuntary piloerection was observed. Most respondents acquired this ability at a young age and executed it easily. VGP occurred with a short latency of less than 10 seconds and longer decay mostly on the arms, with little control of site or laterality.

Although the context in which VGP was used and its effects were not fully reproduced, the association between VGP and involuntary piloerection was suggested at a different point from that reported previously. In contrast to Heathers et al. (2018) who reported that VGP is performed

in activities that cause involuntary piloerection and involves emotional states associated with involuntary piloerection, this study has few such responses and rather emphasizes cold conditions or response. This result may be due to differences in question format. The current study used open-ended questions, which may increase the load of answering questions and lead to fewer answers. Conversely, the present study found that VGP can be boosted by cold and emotional conditions. This result was consistent with the fact that volitional piloerection was easier in situations where involuntary piloerection was likely to be experienced (Maxwell, 1902), suggesting that VGP and normal piloerection may share driving factors.

Additional questions introduced in this study revealed the suitability of VGP for neuroscientific research. Consistent with the study by Heathers et al. (2018), breathing did not affect VGP. A previous study mentioned subtle muscle movements to exercise VGP (Benedek et al., 2010), but body movement was not essential for most respondents in this study. Neither open/closed-eye conditions nor posture affected VGP. In general, VGP had less to do with physical conditions, which proved itself useful for neuroscience studies that are susceptible to movement artifacts. Furthermore, successful VGP exercises in most respondents according to the experimental video demonstrated that this ability can be used in experimental procedures.

3 Study 2

Study 2 aimed to confirm VGP ability and further objectively evaluate the practicability of VGP in experimental procedures. For this purpose, we mailed piloerection measuring devices to VGP holders to conduct a self-execution experiment in which the participants measured piloerection on their own. Additionally, Big Five personality traits were measured to test the relationship between VGP ability and personality traits reported in Heathers et al. (2018). As per Study 1, the study was conducted according to the local ethics committee of Kwansei Gakuin University, and no specific approval procedure was conducted.

3.1 Methods

3.1.1 Participants

Out of 25 VGP holders identified in Study 1, 18 participants were recruited for the study and received 1,500 yen for their participation.

3.1.2 Materials

3.1.2.1 Apparatus

A measuring device was built to obtain objective data of piloerection. Previous studies have proposed several measuring methods including visual inspection (Craig, 2005), image analysis (Benedek et al., 2010; Uchida et al., 2019), and skin-attached sensor (Kim et al., 2014). In this study, an image-based method proposed in Benedek et al. (2010) was employed since it is easy to introduce, and the analysis program (GooseLab) is provided. This method quantifies the strength of piloerection by image processing of the skin surface. The created device has a hollow plastic structure containing a white LED and USB mini camera, and the opening on the opposite side of the camera was fixed to the body surface (lower arm) with a belt to permit camera recording of the skin surface (Figure 1).

3.1.2.2 Experimental video

The same video as Study 1 was used to present the experimental procedure.

3.1.2.3 Questionnaire

The Japanese version of NEO-Five-Factor Inventory (Shimonaka et al., 1999) was used to investigate the Big Five personality traits of the participants.

3.1.3 Procedure

The measuring device was mailed to the participants along with documents providing a general description of the study, instructions for the experiment, and questionnaires. The participants who provided written informed consent to participate completed the VGP experiment and questionnaire. Two participants withdrew their consent, and one participant failed to record

piloerection data, resulting in 15 complete data sets (12 participants from screening and three pre-specified VGP holders).

In the VGP experiment, the participants accessed the experimental video uploaded onto the web, then performed VGP according to the instructed procedure and answered the extent to which they successfully performed VGP on a 6-point scale. During the experiment, the piloerection measuring device simultaneously recorded the skin surface image and audio of the video. The video included five piloerection trials. Participants performed two sessions (10 trials of VGP).

3.1.4 Data analysis

In the preprocessing of video data, the analysis area (26.5 × 26.5 mm) was cut out at 15 fps and resized into 288 × 288 pixels. The video data was then analyzed by GooseLab, and the intensity of piloerection in each frame was obtained. Based on the cues recorded in the audio data, the start and end frames of both rest and piloerection conditions were identified. For each session, a standardized piloerection index was obtained by subtracting the baseline defined as the average amplitude of the five rest periods from the piloerection intensity data (Figure 2).

3.2 Results

3.2.1 Subjective and objective data of VGP

All 15 participants reported that they were able to generate VGP to a greater or lesser extent in both sessions. The minimum session average (5 trials) of subjective ratings of VGP was 0.4, and the average for all sessions was 1.5. Some participants exhibited little or no piloerection upon visual inspection of video recordings. To identify sessions in which VGP was successfully generated based on objective data, the average amplitude of the piloerection index was calculated for each of the five VGP periods included in each session, and the difference from the baseline (i.e., 0) was tested with a one-sample t-test. This resulted in a significant difference in 16 sessions from nine participants (including three pre-specified VGP holders), and the data from these sessions were further analyzed. To examine VGP latency and decay, VGP onsets and offsets were

calculated based on the threshold of 10 % of a response range according to Benedek et al. (2010). VGP onsets and offsets were detected in all trials included in 16 sessions. Onset of VGP occurred on average 3.31 seconds after the start cues of VGP periods ($SD = 2.82$), and the offset occurred on average 10.31 seconds after the end cues ($SD = 5.62$).

To examine the accuracy of subjectively perceived VGP intensity, we calculated the Pearson's correlation coefficients between the subjective ratings and average amplitude of the VGP for five trials in each session. As a result, the relationship between the subjective evaluation of VGP and objective data was inconsistent between individuals and sessions. While positive correlations were observed in five participants, they were negative for two participants, and one participant demonstrated positive and negative correlations for each of two sessions. Correlations for the remaining participant could not be obtained because all subjective ratings were the same value.

3.2.2 Personality characteristics of VGP holders

The personality traits of the participants who provided objective piloerection evidence were compared with normative data. For each of the Big Five domains, the difference between the average score of the participants and normative data was examined using a one-sample t-test with correction for multiple comparisons (Bonferroni method). The results revealed that the score of VGP holders in the Neuroticism domain trended towards being significantly higher than normative data ($t(8)=3.36$, $p = 0.05$, $d = 1.13$).

3.3 Discussion

The results of Study 2 objectively demonstrated that the exercise of VGP indeed elicited piloerection in several participants. Other participants who did not show objective evidence of VGP also reported piloerection. This may be because these individuals had piloerection in body parts other than the forearms. Alternatively, subjective ratings may be formed based on some sort of sensation associated with piloerection, which may have occurred independently of the physical occurrence of piloerection. Deviation of the subjective experience of piloerection from its actual

elicitation may also explain the dissonance between the subjective and objective intensity of piloerection observed in the participants who provided objective data, which emphasizes the importance of objective methods in measurement of piloerection.

In addition, the temporal characteristics of VGP revealed that this ability was practicable during the experimental procedure. Both quantitatively identified latency and decay were shorter than self-reported measures in Study 1, adding group-level evidence to similar data from the previous study (Benedek et al., 2010). The time course of VGP closely resembled the alternation of the rest and VGP conditions, indicating the feasibility of the experimental procedure in which VGP is repeatedly performed at short intervals.

Regarding the personality traits related to VGP, only the neuroticism of the Big Five personality traits showed an association. This result differed from the previous studies of VGP (Heathers et al., 2018) and chills (McCrae, 2007), indicating the importance of openness to experience. The theoretical claim which suggests piloerection is a reaction that is inherently associated with fear seems to support the association between neuroticism and VGP (Huron and Margulis, 2010). In addition, the enhanced interoception associated with neuroticism (Deckersbach et al., 2006; Terasawa et al., 2013) may be involved in the acquisition of VGP through subjective awareness of piloerection.

4 General Discussion

In this study, we investigated the feasibility of VGP in neuroscience research with the expected utility of facilitating the elucidation of mechanisms underlying emotional piloerection. The result demonstrated that VGP is a promising phenomenon to pursue the neural mechanisms of piloerection, mainly through increasing knowledge about physical properties of VGP and acquisition of objective evidence of this ability.

4.1 Group-level evidence of VGP

In this study, individuals with the ability for volitional control of piloerection were identified according to the definition of VGP in a previous study (Heathers et al., 2018), and actual elicitation of piloerection was confirmed by objective measurement. Since previous research on objectively measured volitional piloerection has reported a single case (Maxwell, 1902; Lindsley and Sassaman, 1938; Benedek et al., 2010; Uchida et al., 2019), this study provides the first population-level evidence of this ability.

The identified VGP holders recruited through screening revealed the approximate incidence rate of VGP ability. Approximately 2.8% of screening respondents reported volitional piloerection, and about 36% of participants recruited from such people were classified as VGP holders (Study 1). Among self-reported VGP holders who measured piloerection, 50% were able to induce piloerection on their bodies (Study 2). Taken together, these results imply that approximately 0.5% of the population should have VGP capabilities. Since the incidence of VGP is quite low, identifying individuals with this ability may be a major challenge in utilizing volitional piloerection in neuroscience research. The combined questionnaire and measurements employed in this study provide an effective procedure for identifying VGP holders.

4.2 Feasibility utilizing VGP in neuroscience research

VGP can be performed in accordance with typical experimental procedures and under the physical constraints inherent in neuroscientific measurements. Participants who provided objective VGP evidence in Study 2 could perform this ability at a constant pace according to the given cues. They were able to perform this ability repeatedly at short intervals with rapid onset latency. The temporal characteristics of VGP are advantageous for measurement methods typical in neuroscience research such as block design and signal averaging. Moreover, according to the results obtained in Study 1, most VGP holders could perform this ability irrespective of any physical conditions. These characteristics of VGP are favorable because neuroscientific measurements are susceptible to movement, particularly fMRI which requires tasks to be

performed in a supine position.

4.3 VGP as a research model for involuntary piloerection

The results on the relationship between VGP and involuntary piloerection highlights the potential contribution of VGP to neuroscience research on involuntary piloerection. VGP has previously been reported to be used in situations where piloerection is experienced involuntarily and produces similar emotional results (Heathers et al., 2018). However, the results in this study emphasized the fact that voluntary and involuntary piloerection share antecedent situations and emotional states. This means that studying the emotional factors that promote VGP may permit identification of the mechanisms of involuntary emotional piloerection. For example, by independently controlling the execution of VGP and emotional exposure, it may be possible to differentiate emotional-related neural activities that strengthen VGP (and also arouse involuntary piloerection) from those involved in the generation of piloerection itself.

4.4 Limitations

The objective evidence obtained in this study is partial evidence obtained by a simple procedure. It should be noted that the environment surrounding the participants could not be strictly controlled since the VGP measurements were performed by mail-based self-execution experiments. In addition, findings on the physical conditions and those on the driving factors that enhance VGP are based on self-reports and need to be further verified through experimental studies. Moreover, it will be important to investigate the effects of executing VGP on the activation of other physiological activities. The literature on involuntary piloerection using emotional stimulation suggests that piloerection is accompanied by activity in several ANS substrates. Elucidating the physiological activities associated with VGP may allow us to distinguish the activation patterns of the sympathetic nervous system inherent in piloerection from the autonomous activities caused by specific antecedent emotional stimuli.

In conclusion, this study provided objective evidence that supports the utility of VGP in

neuroscience research. Our findings on the commonality between VGP and involuntary piloerection suggest that this ability may at least partially contribute to the study of involuntary piloerection. VGP can be utilized not only in research on piloerection as a pure physiological phenomenon, but also in neuroscience research on emotions.

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Table 1. The characteristics of VGP

Outline of VGP							
Execution method*	Bodily focusing	Recall of involuntary piloerection sensation	Direct volition				
Number of respondents (%)	15 (60)	10 (40)	6 (24)				
Subjective difficulty	Very easy	Easy	Difficult	Very difficult			
	6 (24)	11 (44)	7 (28)	1 (4)			
Physical response							
Sites of piloerection*	Arms	Legs	Neck	Back	Face	Chest	Head
	24 (96)	9 (36)	4 (16)	3 (12)	3 (12)	2 (8)	1 (4)
The most intense site	Arms	Face	Legs	Neck	Back		
	20 (80)	2 (8)	1 (4)	1 (4)	1 (4)		
Control of cites and laterality †	Cites	Laterality					
	2 (8)	2 (8)					
Latency of piloerection	Less than 5 sec	5-10 sec	More than 10 sec				
	20 (80)	3 (12)	5 (20)				
Decay of piloerection	Less than 5 sec	5-10 sec	More than 10 sec				
	10 (40)	7 (28)	8 (32)				
Associated physical sensations*	Chills	Tingling	Cold sensation	Numb			
	21 (84)	2 (8)	2 (8)	1 (4)			
Associated physical reactions*	Tremor	Muscle tension	Temperature change	Respiratory change	Lacrimation		
	5 (20)	4 (16)	1 (4)	1 (4)	1 (4)		
Context of VGP							
Enhancing involuntary piloerection	Yes	No					
	8 (32)	17 (68)					
Activities where VGP is used*	Cold environment	Emotional experience	As a performance				
	4 (16)	2 (8)	1 (4)				
Effects of VGP*	Temperature elevation	Resolving discomfort	Communicating emotion	Enhancing emotin			
	2 (8)	2 (8)	1 (4)	1 (4)			
Promoting situation of VGP*	Cold environment	Emotional experience	Relaxing environment	Fever	Inspiration		
	7 (28)	6 (24)	2 (8)	2 (8)	1 (4)		
Physical conditions							
Body movement	Not necessary	Desirable but not necessary	Necessary				
	15 (60)	9 (36)	1 (4)				
Eye conditions#	Open-eye	Closed-eye					
	23 (92)	24 (96)					
Posture#	Upright	Sitting	Supine				
	23 (92)	24 (96)	22 (88)				
Promoting situation of VGP*	Cold environment	Emotional experience	Relaxing environment	Fever	Inspiration		
	7 (28)	6 (24)	2 (8)	2 (8)	1 (4)		

*: multiple answers possible, †: number of respondents answering “controlable”, #: number of respondents answering “practicable”

Figure 1. A schematic diagram of piloerection measuring device.

Figure 2. Typical data of piloerection index. The horizontal solid line denotes baseline, and the dashed line represents threshold (10% of a maximum response range).