Changes in emotional state while holding a slimy fluid in the palmar skin

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Abstract
Various effects have been observed when a slimy fluid is held in palmar skin. The observed effects include friction control of the skin and cleansing and moisturizing of the skin. However, few reports exist regarding the changes in the emotional state of persons when a slimy fluid is held in their palmar skin, even though the viscosity properties of the fluid affect emotional changes. Thus, this study investigates the emotional changes due to holding slimy fluid in the palmar skin by evaluating heart rate variability (HRV) and sensibility. Newtonian and non-Newtonian fluids, with viscosities ranging from 0.01 to 100 Pa·s, were prepared. Eight male subjects in their 20s soaked their palms in the slimy fluid without seeing it. At the room temperature of 25 °C, the subjects moved their palms freely for 1 min. They were allowed to rub their palms together. During the experiments, the HRV was recorded. A frequency analysis was performed for estimating autonomic nerve activity. After holding the fluid, the subjects were asked to provide feedback through the semantic differential method. Significant changes in autonomic nerve activations were observed when the subjects soaked their palms in the slimy fluid. The high viscosity Newtonian fluid reduced the parasympathetic nervous system activity. These changes in the psychophysiological indexes influenced the feelings of the subjects ascertained according to the semantic differential method. A relationship between the characteristic of the slimy fluid and a psychophysiological index can improve the efficiency when developing products exposed to human skin.

Keywords: Slimy liquid, Newtonian fluid, Non Newtonian fluid, Skin, Emotions, R-R interval, Sympathetic nerve, Parasympathetic nerve

1. Introduction

The skin is the largest organ of the human body, nearly covering it entirely. Moreover, the skin is a multi-functional interface against the body outside parts, which consists of three layers, the epidermis, dermis, and subcutaneous tissue (Limbert et al., 2019). Although the humidity and temperature affect the skin friction, the friction generated between the skin and the contacting surface is properly regulated to support activities of daily living and avoid skin injury (Klaassen et al., 2017; Morales-Hurtado et al., 2017; Klaassen et al., 2016; Meredith et al., 2015). The friction generated on the skin surface also provides us with tactile perceptions derived from the mechanoreceptors in each layer of the skin (Hamasaki et al., 2018). The mechanoreceptor is a sensory receptor responding to the mechanical deformation of the skin. The receptors are represented by Merkel cells, Meissner corpuscles, Ruffini endings, and Pacinian corpuscles. Merkel cells are located at the base of the dermal papillae (the interface between the epidermis and the dermis, which have a ridge-like shape) and allow the perception of pressure and slow stimulus. Ruffini endings are within the dermis and allow the recognition of the skin stretching. Meissner corpuscles are located at the top of dermal papillae and allow the perception of dynamical transverse deformation of the skin. Pacinian corpuscles are located within the subcutaneous tissue and help us recognise vibrations. Human fingers have a high density of tactile receptors than other body parts. Therefore, fingers can obtain finer tactile information than other body parts (Zhanga et al., 2017). Changes in mechanical states, such as
stress and strain distributed around the tactile receptors aroused when a mechanical stimulus is applied to the skin, have been explored (Sergachev et al., 2019; Liu et al., 2017).

The tactile perception affects emotional change (Arvidsson et al., 2017). Thus, the mechanical stimuli to the skin surface for emotional changes apply from hard surfaces and slimy fluids because the slimy characteristics can apply the shear stress and pressure distribution onto the skin surface (Gore et al., 2018). The same phenomena also occurred in the oral cavity, where the masticatory stimulation or the stimulation to mucosa from masticated food affected emotional changes. Several studies have elucidated those complex and multi-physics phenomena (Kieserling et al., 2018; Tsue et al., 2016; Cai et al., 2017; Nakano et al., 2013).

This study investigates the emotional changes due to holding a slimy fluid in the palmar skin by using a psychophysiological index. In this regard, various physiological conditions are correlated with cardiac autonomic function (Olshansky et al., 2008; Thayer et al., 2010). Heart rate variability (HRV) is a marker of cardiac autonomic modulation, which is the physiological phenomenon of the variation in the time interval between consecutive heartbeats in milliseconds. The physiological correlations of HRV and standards for its measurement have been proposed (The Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). In general, spectral analysis of the HRV is performed and evaluated for assessing mental stress and stimulation in humans (Pagani et al., 1989; Toichi et al., 1997; Shibahara et al., 1996). Finally, a conventional semantic differential method as a sensibility evaluation was also performed (Bakker et al., 2014; Lorr et al., 1988; Bradley et al., 1994; Valois et al., 1991; Russell et al., 1980). This would be expected for further understanding of the results of the HRV analysis.

2. Materials and Methods

2.1 Preparation of the slimy fluids

Water solutions of polyvinyl alcohol (PVA) as a Newtonian fluid (NF) were prepared (Table 1). For a low viscosity fluid (NF-L), medium viscosity fluid (NF-M), and high viscosity fluid (NF-H), 10 wt% of PVA (molecular weight: \(1.0 \times 10^3\)), 15 wt% of PVA (molecular weight: \(1.0 \times 10^3\)), and 5.0 wt% of PVA (molecular weight: \(3.5 \times 10^3\)) were used, respectively. Water solutions of polyethylene glycol (PEG) as a non-Newtonian fluid (NonNF) were also prepared. For a low viscosity fluid (NonNF-L), medium viscosity fluid (NonNF-M), and high viscosity fluid (NonNF-H), 0.5 wt% of PEG (molecular weight: \(2.0 \times 10^6\)), 2.75 wt% of PEG (molecular weight: \(2.0 \times 10^6\)), and 5.0 wt% of PEG (molecular weight: \(2.0 \times 10^6\)) were used, respectively. Each solute was dissolved with distilled water, and the slimy fluids were stirred for 3 days at 50 °C for their hydration.

Table 1 Constituents of slimy fluids.

|                     | Low viscosity (L) | Medium viscosity (M) | High viscosity (M) |
|---------------------|-------------------|----------------------|--------------------|
| **Newtonian fluid (NF)** |                  |                      |                    |
| Molecular weight    | \(1.0 \times 10^3\) | \(1.0 \times 10^3\)  | \(3.5 \times 10^3\) |
| Water solution concentration | 10 wt% | 15 wt% | 5.0 wt% |
| **Non-Newtonian fluid (NonNF)** |          |                      |                    |
| Molecular weight    | \(2.0 \times 10^6\) | \(2.0 \times 10^6\)  | \(2.0 \times 10^6\) |
| Water solution concentration | 0.5 wt% | 2.75 wt% | 5.0 wt% |

Figure 1 shows the considered viscosities of the slimy fluids, measured using a cone-plate viscometer (BROOKFIELD DV-II+). As seen in the figure, the viscosity of the NonNF decreases when the shear rate increases; these characteristics are also found in natural synovial fluid and natural foods (Nakanishi et al., 1999; Zhu et al., 2017).
Fig. 1 Viscosities of the considered slimy fluids. Newtonian fluids (NF) consisted of a water solution of PVA, and non-
Newtonian fluids (NonNF) consisted of a water solution of PEG.

2.2 Experimental procedures

Eight male subjects in their 20s participated in the experiment. All procedures were in accordance with the 1964
Helsinki declaration and its later amendments or comparable ethical standards. The ethical approval for the experiments
was obtained from the ethical review committee of the Faculty of Advanced Science and Technology, Kumamoto
University, Japan. Informed consent was obtained from all individual subjects. None of the experiments were invasive
or physiologically or psychologically harmful. All data were stored anonymously, participations were voluntary, and the
subjects had the right to quit at any time if they desired.

Figure 2 summarises the experiment. The subject wore the heart rate sensor (myBeat, WHS-1, UNION TOOL Co.,
Japan) and took a seat for resting position for 1 min. The subject soaked their palms in the slimy fluid (200 ml, 33 °C)
without seeing the fluid at a room temperature of 25 °C. The subject could move their palms freely and was allowed to
rub their palms together for 1 min. During the experiment, electrocardiograms (ECG) were recorded at a sampling
frequency of 1.0 kHz. After holding the fluid, the subject was asked to provide feedback following the semantic
differential method.

Every subject held all the slimy fluid (six fluids in total, Fig. 1). The order for fluid was randomly assigned. When
the subject replaced the other fluid, the time of rest was set to more than 30 minutes. Almost all the subjects took 2–3
days to complete all the tests.

Fig. 2 Experimental overview: changes in the emotional state while holding a slimy fluid in the palmar skin.
2.3 ECG processing

The ECG obtained during the testing was processed for estimating autonomic nerve activity. The autonomic nerve system comprises two anatomically- and functionally-distinct divisions, the sympathetic nervous system and the parasympathetic nervous system (McCorry, 2007). The sympathetic nervous system predominates during emergency ‘fight-or-flight’ reactions and exercise. Under these conditions, the overall effect of the sympathetic nervous system is to prepare the body for strenuous physical activity. In contrast, the parasympathetic nervous system predominates during quiet, resting conditions. The overall effect of the parasympathetic system under these conditions is to conserve and store energy and regulate basic body functions such as digestion and urination.

Figure 3 shows the data processing procedures (Pagani et al., 1989; Bakker et al., 2014) that are performed by using a standard software program for the heart rate sensor (Acc Analyzer, UNION TOOL Co., Japan). The HRV, which is the physiological phenomenon of the variation in the time interval between consecutive heartbeats in milliseconds (R-R interval), was obtained from the recorded ECG. The power spectrum density of the R-R interval between 60 s was analysed using the fast Fourier transformation (FFT). From the power spectrum density of the R-R interval, two power components—the low frequency (LF; area under 0.05–0.15 Hz) and the high frequency (HF; area under 0.15–0.40 Hz)—are calculated. The LF component is influenced by autonomic nerve activity, while the HF component is only influenced by parasympathetic nerve activity. Therefore, the LF/HF ratio is considered to indicate the activity of the sympathetic nerve. Figure 4 shows the calculation method of the increase–decrease rates of the LF and LF/HF. The mean value for each power of HF or LF/HF between 60 s before contacting or ending contact with the slimy fluids is calculated, respectively (HF\textsubscript{Before}, HF\textsubscript{After}, LF/HF\textsubscript{Before}, LF/HF\textsubscript{After}), and the increase–decrease rates are calculated by using those values. The increase–decrease rate is represented as a single line graph for each subject.

![Fig. 3 Data processing for estimating autonomic nerve activity.](image-url)
2.4 Sensibility evaluation

The conventional semantic differential scales using a 7-point scale between polar adjectives was conducted to evaluate the sensibility evaluation after the experiment (Bradley et al., 1994; Valois et al., 1991) (Figure 5). The bipolar adjective pairs were selected (boring–fun, melancholy–happy, creepy–comfortable, not enough–satisfied, nervous–relaxed). The six pairs could be arranged in an environmental psychology model with two axes showing various adjectives to indicate the level of pleasure (X-axis) and awakening (Y-axis) (Bakker et al., 2014; Russell, 1980). The results of semantic differential scales for each subject were re-arranged to the environmental psychology model, and the polygon figure was grey-coloured. The individual polygon figures were superimposed for estimating the overall trend of all subjects.

3. Results and Discussion

Figure 6 shows the influence of the low viscosity slimy liquid on the changes in the emotional state. The increase–decrease rates in the LF/HF and HF differ between individuals, while in some subjects increase, in others decrease so that no similar tendency due to the slimy liquid is observed. In the semantic differential method, the superimposed areas (the areas shaded dark) were unclarity. These results suggest that the subjects experienced several different emotions when contacting the low viscosity Newtonian fluid (NF-L).

Figure 7 shows the influence of the medium viscosity slimy liquid on the changes in the emotional state. The increase in the viscosity of the Newtonian fluid decreases the increase–decrease rate of the HF (From NF-L to NF-M). Almost all the subjects decreased the HF power. Moreover, some subjects experienced discomfort because ‘creepy’ was selected in the semantic differential method. The superimposed area (the area shaded dark) became clear, and the area is shifted to the ‘Unpleasant’ part.

Figure 8 shows the influence of the high viscosity slimy liquid on the changes in the emotional state. Further increase in the viscosity of the Newtonian fluid (NF-H) might present negative stress in various subjects because they reported feeling ‘creepy’, ‘melancholy’, and ‘boring’. The superimposed areas (the areas shaded dark) are shifted to the ‘Unpleasant’ part. However, some subjects showed fascinating feelings (‘surprised’, ‘fun’, and ‘satisfied’). It was supposed that the high viscosity Newtonian fluid (NF-H) was also predisposed to reduce the HF power. Non-Newtonian fluid (NonNF-H) was thought to provide approximately similar results. However, the fascinating feelings levels for NonNF-H (‘surprised’, ‘fun’, and ‘satisfied’) are lower than those for the Newtonian fluid (NF-H).
The Newtonian fluids might provide different feelings among individuals (NF-L, M, and H); some subjects presented negative stress, whereas some expressed fascinating feelings. When using non-Newtonian fluids (NonNF-L, M, and H), the variations between the subjects appeared to be small, and almost all the subjects showed similar feelings.

It was concluded that the increase–decrease rates of the LF/HF and HF could not indicate changes in the emotional state perfectly. However, it was evident that a higher viscosity of the Newtonian fluid (NF-M and H) decreased the HF power. The HF component is influenced by parasympathetic nerve activity. The parasympathetic nervous system predominates during quiet, resting conditions. The decreased activities of the parasympathetic nervous system may be highly relevant to negative feelings (‘creepy’, ‘melancholy’, and ‘boring’).

Although the increase–decrease rates of the LF/HF and HF in each subject were individually changed by contacting the non-Newtonian fluids (NonNF-L, M, and H), the subjects did not share a common feeling. Furthermore, the variations of feelings between the subjects seemed to be small because it was evident that the superimposed areas were clearly shifted to the “Unpleasant” part compared to those considering the Newtonian fluids (NF-L, M, and H). The results indicated that almost all the subjects presented similar feelings. Those results were thought to be derived from the non-Newtonian fluids’ characteristics. The non-Newtonian fluids prepared for the experiments showed that the viscosity was decreased when the shear rate increased, and these characteristics were also found in natural synovial fluid and natural foods. The fluid characteristics might provide a ‘natural way of stimulation’ to the subjects, and the unexpected stimulation, leading to a sudden response, might be avoided.
Fig. 6 Changes in the emotional state while holding a slimy fluid in the palmar skin. Medium viscosities of Newtonian fluid (NF-L) and non-Newtonian fluid (NonNF-L) were used.

Fig. 7 Changes in the emotional state while holding a slimy fluid in the palmar skin. Medium viscosities of Newtonian fluid (NF-M) and non-Newtonian fluid (NonNF-M) were used.
6. Conclusions

The emotional changes due to holding a slimy fluid in the palmar skin were studied considering the HRV and the sensibility evaluation (semantic differential method). Eight male subjects in their 20s participated in the experiment.

The higher viscosity of the Newtonian fluid decreased the HF power (parasympathetic nerve activities), which may be highly relevant to the negative feelings (‘creepy’, ‘melancholy’, and ‘boring’). However, using even higher viscosity of the Newtonian fluid, some subjects showed fascinating feelings (‘surprised’, ‘fun’, and ‘satisfied’).

By contacting the non-Newtonian fluids, the variations of feelings between the subjects appeared to be small, and almost all the subjects showed similar feelings. However, the increase–decrease rates of the LF/HF and HF in each subject changed individually, and the subjects did not share a common feeling. The fluids’ characteristics were similar to those of the natural synovial fluids and natural foods. The fluid characteristics might provide a ‘natural way of stimulation’ to the subjects, and the unexpected stimulation, leading to a sudden response, might be avoided.

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