Sakai et al. Journal of Physiological Anthropology (2020) 39:22
https://doi.org/10.1186/s40101-020-00234-w

Journal of
Physiological Anthropology

METHODOLOGY ARTICLE Open Access

Useful parameters for the motion analysis of facial skin care in Japanese women

Shingo Sakai[1*], Ruako Takatori[2,3], Mika Nomura[4] and Kuniaki Uehara[2]

Abstract

Background: Facial skin care (FSC) is an important routine for Japanese women. Hand motions during FSC physically affect psychological state. However, it is very difficult to evaluate hand motions during personal and complex FSC. The objective of this study was to find out objective and quantitative parameters for hand motions during facial skin care (FSC). Women who enjoy and soothe during FSC (Enjoyment group (E group), $n = 20$) or not (non-enjoyment group (NE group), $n = 19$) were recruited by an advance questionnaire. The same lotion, emulsion, and cream were provided to all subjects, and they used sequentially in the same way as the women's daily FSC. The motion of the marker on the back side of the right middle finger during FSC was tracked by a motion capture system. The heart rate variability (HRV) was also measured before and after FSC for evaluating psychological effect.

Results: The averaged acceleration (Avg. ACC), approximate entropy (ApEn), and power law scaling exponent (Rest γ) of the cumulative duration of slow motion from the sequential data of acceleration were evaluated. Compared to the NE group, the E group showed a lower Avg. ACC when using emulsion ($p = 0.005$) and cream ($p = 0.007$), a lower ApEn when using emulsion ($p = 0.003$), and a lower Rest γ ($p = 0.024$) when using all items, suggesting that compared to the NE group, the E group had more tender and regular motion, and sustainable slow motions, especially in the use of emulsion. In the E group, the low/high-frequency component of HRV decreased significantly after FSC, suggesting suppression of sympathetic activity ($p = 0.045$). NE group did not. For all subjects, ApEn and Rest γ showed significantly positive correlation with the increase in the low/high-frequency component of HRV after FSC ($p < 0.01$). ApEn showed significantly negative correlation with the increase in the high-frequency component of HRV after FSC ($p < 0.05$). Avg. ACC did not show significant correlation with them. These results suggested that the behavior of FSC influences the autonomic nerve system.

Conclusions: ApEn and Rest γ are useful parameters for evaluating quality of hand motions during FSC.

Keywords: Facial skin care, Motion capture, Autonomic nerve system, Relaxation, Approximate entropy, Power law scaling exponent

* Correspondence: sakai.shingo2@kao.com
[1]Skincare Products Research, Kao Corporation, 5-3-28, Kotobuki-cho, Odawara, Kanagawa 250-0002, Japan
Full list of author information is available at the end of the article

Background

Facial skin care (FSC) is important in maintaining and improving skin function. Ingredients of FSC products are known to improve skin problems such as wrinkles, spots, and rough skin texture [1, 2]. Furthermore, the use of certain hand motions during FSC is expected to have beneficial physiological effects. FSC of Japanese woman has also been reported to influence autonomic nerve system (ANS) activity [3–7]. Alternatively, facial massage by hand is thought to provide physical stimulation to both skin and muscle, leading to morphological and physical improvement [8, 9].

Moreover, FSC combines not only cultural aspects for beauty but also the sociological significance based on communication. It is important to expand the psychological and physiological potential of user by providing the method of FSC.

However, since FSC behavior is very personal and complicated, objective and quantitative evaluation is difficult. There are very few reports on the relationship between hand motions during FSC and physiological changes.

We focused on two parameters, the approximate entropy (ApEn) [10] used for the analysis of complex systems and Rest γ [11] representing the cumulative frequency distribution of human-activity duration for the evaluation of FSC motions. ApEn can be used to evaluate the complexity of information, even for discrete data with finite length [10, 12]. ApEn is smaller in the case of more regular sequenced data. Pincus et al. reported on the risk of sudden infant death syndrome by ApEn using electrocardiogram data [13], while Arif et al. evaluated the change in the stability of walking with aging by ApEn [14]. On the other hand, Nakamura et al. proposed Rest γ as an appropriate living activity index [11]; they binarized sequenced acceleration data, recorded by a locomotor, with the averaged value; from this, the logarithm of the cumulative duration and frequency from sequenced data of the duration of motions smaller than the average value was calculated, and the slope taken as the Rest γ value. Furthermore, they reported that Rest γ indicated qualitative differences in the living activities between healthy and depressed individuals [15].

Many relationships between skills and motion have been reported in the fields of sport [16–18], music [19], and dance [20]. Self-facial massage of Japanese women stimulates the parasympathetic nerve, suggesting a relaxation effect [3, 5–7]. Daily FSC may have the ability to control ANS unconsciously. In these studies, ANS activity is evaluated by heart rate variability (HRV) [21]. HRV, the cardiovascular signal variability of the R–R period, is a commonly adopted marker of cardiac ANS activity, which is both reliable and non-invasive [21]. The frequency of HRV has been analyzed using methods such as fast Fourier transform (an autoregressive model) and maximum entropy methods (MEMs). When the power is separated between high frequency (HF; 0.15–0.45 Hz) and low frequency (LF; 0.04–0.15 Hz) in spectral analysis, the HF reflects the activity of the parasympathetic nervous system and the LF reflects the activities of both the sympathetic and parasympathetic nervous system [22]. The ratio of LF and HF (L/H) can therefore be used as an index of sympathetic nervous system activity [23]. The change of HRV is also closely related to emotional change [24–26].

This study involved two female groups, recruited by advance questionnaire; one group consisted of women who enjoyed and soothed during FSC (E group) and the other group consisted of women who did not enjoy or soothe during FSC (NE group). The FSC behavior of both groups was compared by ApEn and Rest γ. Moreover, we compared the effect of hand motions during FSC on ANS activity change in both groups and the relationship between parameters of FSC motion and ANS activity change.

Methods

Subjects

This study included healthy females between 31 and 49 years of age. Subjects who smoked, had skin issues (such as atopic dermatitis), were taking medication, or had received cosmetic surgery were excluded from this study. Subjects used all three items (lotion, emulsion, cream) every day for skin care. Subjects were selected and classed into two groups by the advance questionnaire. The advance questionnaire had two questions: “Do you enjoy during daily FSC?” and “Do you soothe during daily FSC?”. Female answering “Yes” and “No” to both were classed into enjoyment group (E group, n = 20; averaged age, 40 ± 4) and non-enjoyment group (NE group, n = 19; averaged age, 41 ± 5), respectively. The difference in the age of both groups was not significant (p = 0.470). There was no significant difference in subjective skin care time between the two groups (E group, 7.6 ± 3.0 min; NE group, 7.4 ± 3.2 min, p = 0.860). All subjects used the same commercially available skincare items (lotion, emulsion, and cream) for FSC in this study.

Procedure

Subjects were instructed to wear a headband and ring with marker on a chair, at a table, in front of a mirror, for 10 min, and use the lotion, emulsion, and cream sequentially in the same way as their daily FSC. The room was air-conditioned (25 ± 1 °C; humidity, 50% ± 5%), and HRV was measured for 3 min before and after FSC.

The characteristics of items used are shown below.

The lotion:

A typical lotion solubilized with nonionic and silicone surfactants, providing compatible feeling to the skin.

The emulsion:

A typical O/W emulsion combining anionic surfactant and thickener, providing compatible feeling to the skin and elastic feeling.

The cream:

A typical O/W cream with a large amount of water-holding oil, providing soft and fast compatible feeling to the skin. The cream is softer than normal massage one.

Measurement

To measure motion of light hand during FSC, 10-mm reflective markers were affixed to the back side of the base of the right middle finger and on both ends and middle of the head band (Fig. 1). Trajectories were recorded using a 6 camera, three-dimensional motion capture system, sampling at 100 Hz (VENUS3D v.4.1, Nobby Tech Co., Tokyo, Japan).

To measure the HRV of subjects, the left forearm and right ankle of the subjects was fixed by clip-type electrodes (TE-43, Fukuda Denshi Co., Ltd., Tokyo) for electrocardiogram (ECG) monitoring. The HRV was recorded with a Marquette Holter recorder (LRR-03; GMS, Inc., Tokyo, Japan) for 3 min before and after FSC. HRV data were processed using HRV analysis software (Crosswell, Inc., Tokyo, Japan) [27–31].

Data analysis

The space of the trajectories of the marker on the right middle finger was fixed by a plane and determined by the 3 points on the head band. Sequenced data of acceleration of the marker on the right middle finger was calculated from the corrected trajectory data. ApEn and Rest γ were calculated from the sequenced data of acceleration.

Fig. 1 Positions of reflective markers. Circle, position of markers

Approximate entropy (ApEn)

ApEn is a complexity parameter of information entropy [10, 32]. It can be applied to finite length and discrete data and is calculated by the following formula [32, 33].

A sequenced data: $a = a(1), a(2), \ldots, a(n)$

$$\mathrm{ApEn}(\mathrm{m,r}) = -\left((n-m)^{-1}\sum_{i=1}^{n-m}\log\frac{C_i^{m+1}(r)}{C_i^m(r)}\right)$$

$$C_i^m(r) = \sum_{j=1}^{n-m+1} C_{ij}$$

$$C_{ij} = \begin{cases} 1, if\,\|x(i)-x(j)\|\infty \le r \\ 0,\ \ otherwise \end{cases}$$

$$x(i) = [a(i), \ldots, a(i+m-1)]$$

n = length of data

m = length of compared subsequence

r = tolerance for noise

In this study, 2, 500, and 0.15 x (standard deviation) were substituted for n, m, and r, respectively, according to the mathematical theory of Pincus [12]. The window of length of compared subsequence (500 points) was calculated and moved from the start to the end, and the averaged ApEn was determined; a smaller ApEn being indicative of a more regular motion.

Rest γ

Using a locomotor, Nakamura et al. demonstrated that the cumulative probability distribution of resting periods in life takes a scale-free power-law form [15]. Rest γ was proposed as a scaling exponent for evaluating quality of life [15, 34, 35]. The sequenced acceleration data was processed according to the method as described by Nakamura et al. [15]. Sequenced data was binarized into “resting periods” or “active periods” by a threshold of averaged acceleration (Fig. 2). Rest γ is a scaling exponent which indicates the cumulative distribution of the frequency for resting periods (Fig. 3). In this study, a lower Rest γ demonstrated a longer sustainability of slow motion or hand pressure.

HRV

The power spectrum of a time series of the R-R interval was calculated using the maximum entropy method. The LF and HF power were estimated to be within the 0.04–0.15 and 0.15–0.45 Hz frequency bands, respectively. The LF/HF ratio and HF were taken as parameters of sympathetic and parasympathetic nerve activity,

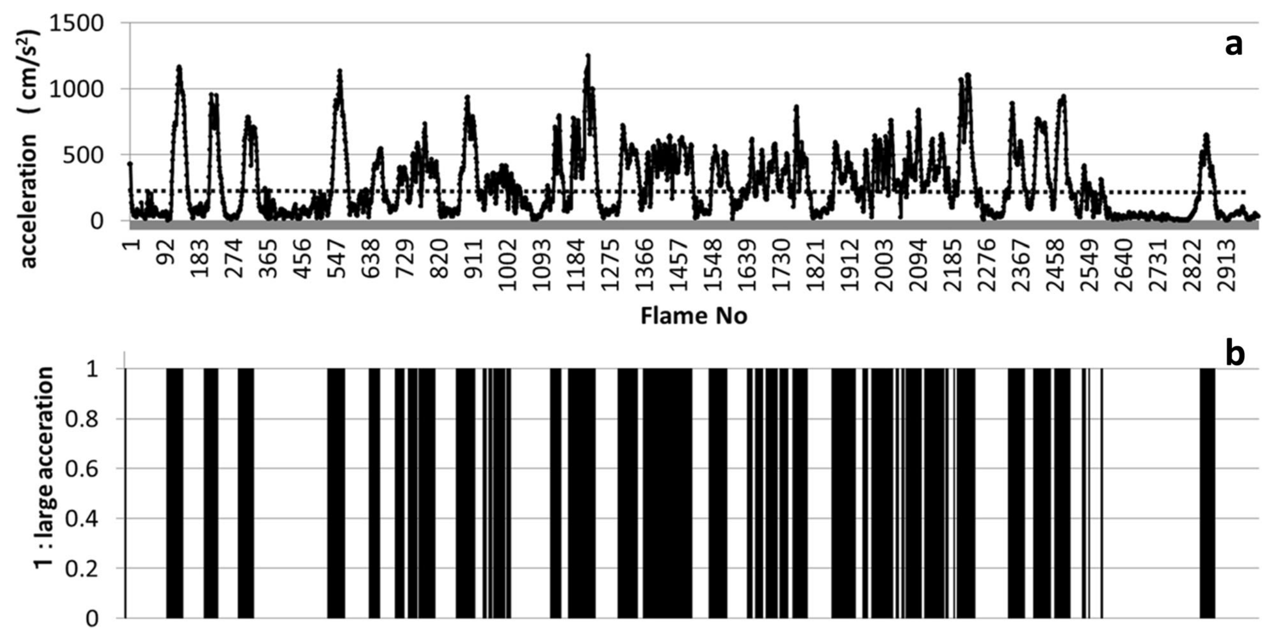

Fig. 2 Calculation for Rest ϒ (1). **a** Acceleration series data of marker on right hand is binarized by the averaged acceleration (dashed line). **b** Binarized log of duration of fast motions (black) and slow motions (white) from data **a**

respectively [23]. The coefficient component of variance (ccv) of the LF/HF ratio and the HF were calculated using the following formula [36]:

$$\text{ccvHF} = \sqrt{\text{HF}}\ (\text{ms}^2)/\text{R-R interval (ms)}\times 100$$

$$\text{ccv(LF/HF)} = \sqrt{(\text{LF/HF})}/\text{R-R interval (ms)}\times 100$$

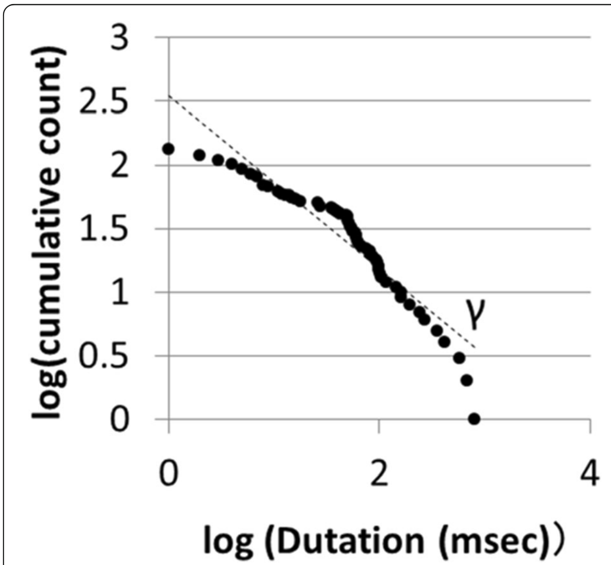

Fig. 3 Calculation for Rest ϒ (2). Cumulative distributions of duration of slow motions (white in Fig. 1). The slope (Rest ϒ) is determined by the method of least squares

Statistical analysis

All data were analyzed by SPSS (v.25). The effect of time and group was multi compared by the Bonferroni correction method after two-way repeated measures ANOVA. Correlation was analyzed by the Pearson's simple correlation analysis.

Results

Difference in motion parameters between groups

Averaged acceleration (Avg. ACC), ApEn, and Rest γ when using each item (lotion, emulsion, and cream) during FSC in both groups were calculated and compared.

With regard to the averaged acceleration, the tendency of interaction between the group and item was analyzed by a two-way repeated measures ANOVA (F (1,37) = 2.441, p = 0.094). The simple main effect of the item was not significant at the group level (NE group, F (2,36) = 1.596, p = 0.217; E group, F (2,36) = 0.818, p = 0.449). The simple main effect of the group was however significant at the level of emulsion and cream (lotion, F (1,37) = 2.139, p = 0.152; emulsion, F (1,37) = 9.127, p = 0.005; cream, F (1,37) = 8.092, p = 0.007). The acceleration of emulsion (p = 0.005) and cream (p = 0.007) in the E group was significantly smaller than that of the NE group by multivariate ANOVA (Fig. 4a). With regard to the acceleration when using the lotion, the difference between both groups was not significant by multivariate ANOVA (Fig. 4a). These results suggest that the E group has a lower acceleration (gentle motions) than the NE group when using emulsion and cream.

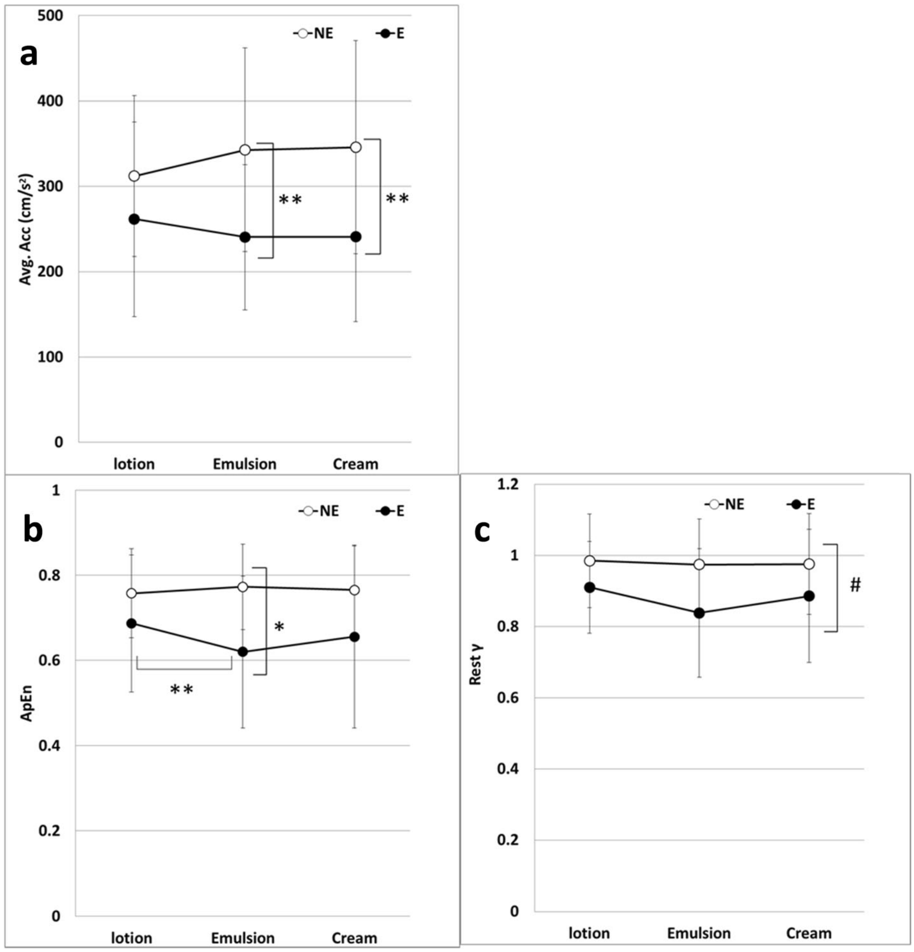

Fig. 4 The change of motion parameters during FSC. E, enjoyment group (n = 20); NE, non-enjoyment group (n = 19). *$p < 0.05$; **$p < 0.01$ multiple comparison (Bonferroni correction); $^{\#}p < 0.05$ (main effect of group by ANOVA)

With regard to the ApEn, the relationship between the group and item was also observed by two-way repeated measures ANOVA (F (1,37) = 2.612, p = 0.080). The simple main effect of items in the E group was significant at the group level (NE group, F (2,36) = 0.412, p = 0.666; E group, F (2,36) = 8.508, p = 0.001). The ApEn of the emulsion was significantly smaller than that of lotion (p = 0.001) in the E group by multivariate ANOVA (Fig. 4b). The simple main effect of the group was significant at the level of emulsion (lotion, F (1,37) = 2.469, p = 0.125; emulsion, F (1,37) = 10.163, p = 0.003; cream, F (1,37) = 3.856, p = 0.057). The ApEn of emulsion (p = 0.003) in the E group was significantly smaller than that of the NE group by multivariate ANOVA (Fig. 4b). These results suggest that the ApEn of emulsion is lower than that of lotion in the E group compared to the NE group.

With regard to the Rest γ, the interaction between the group and item was not significant by two-way repeated measures ANOVA (F (1,37) = 0.996, p = 0.374). The main effect of the group was significant (F (1,37) = 5.522, p = 0.024) (Fig. 4c). The tendency of main effect of item was observed (F (1,37) = 3.174, p = 0.054). Multiple comparisons showed that the Rest γ of emulsion was significantly lower than that of lotion (p = 0.049). These results suggest that the E group has a lower Rest γ than the NE group.

Differences in the effects of FSC on ANS activity between groups

With regard to ccv(LF/HF), the interaction between the time and group was significant by two-way repeated measures ANOVA (F (1,37) = 4.962, p = 0.032). The simple main effect of time in the E group was significant at the group level (NE group, F (2,36) = 0.737, p = 0.396; E group, F (2,36) = 5.339, p = 0.027) (Table 1). Multivariate ANOVA showed that the ccv(LF/HF) significantly lowered after FSC in the E group (p = 0.013).

The simple main effect of the group was significant at the level of time (before, F (1,37) = 10.453, p = 0.003; after, F

Table 1 The change of HRV by FSC

	ccv (LF/HF)			ccv (HF)		
	before	after	p (1)	before	after	p (1)
NE	0.104±0.043 (0.084−0.126)	0.116±0.051 (0.091−0.141)	0.396	1.816±0.880 (1.380−2.252)	1.639±0.800 (1.243−2.035)	0.02*
E	0.206±0.126 (0.146−0.266)	0.177±0.114 (0.122−0.231)	0.027*	1.383±0.699 (1.048−1.718)	1.408±0.762 (1.041−1.774)	0.732
p (2)	0.03*	0.045*		0.105	0.373	

NE, non-enjoyment group (n = 19); E, enjoyment group (n = 20); p (1), before vs after, multiple comparison (Bonferroni correction); p(2), NE vs E, multiple comparison (Bonferroni correction)
*p < 0.05

(1,37) = 4.315, p = 0.045) (Table 1). Multivariate ANOVA showed that the ccv(LF/HF) significantly lowered after FSC in the E group (p = 0.013). Multivariate ANOVA showed that the ccv(LF/HF) of the E group was higher than that of the NE group before and after FSC. These data showed that the ccv(LF/HF) in the E group was higher than that of the NE group and decreased after FSC.

With regard to ccv(HF), the tendency of the interaction between time and group was analyzed by two-way repeated measures ANOVA (F (1,37) = 3.926, p = 0.055). The simple main effect of time in the NE group was significant at the group level (NE group, F (2,36) = 5.912, p = 0.020; E group, F (2,36) = 0.119, p = 0.732) (Table 1). Multivariate ANOVA showed that the ccv(HF) significantly lowered after FSC in the NE group (p = 0.020). The simple main effect of the group was not significant at the level of time (before, F (1, 37) = 2.766, p = 0.105; after, F (1,37) = 0.812, p = 0.373) (Table 1). These data show that the ccv(HF) in the NE group significantly decreases after FSC. These data suggest that effects of FSC on HRV may be different between the NE and E groups.

The relationship between motion parameters and the change in HRV following FSC

Both ApEn and Rest γ correlated significantly with the change of ccv(LF/HF) following FSC. Moreover, ApEn significantly correlated with the change of ccv(HF) following FSC (Table 2, Fig. 5). Both parameters showed high correlation especially in the case of emulsion. Averaged accelerator (Avg. ACC) was not correlated with

Table 2 Relationship between motion parameters and changes of HRV by FSC

	⊿ccv (L/H)	⊿ccv (HF)
ApEn (Lotion)	0.439** (0.005)	−0.386* (0.015)
ApEn (Emulsion)	0.549*** (<0.001)	−0.433** (0.006)
ApEn (Cream)	0.449** (0.004)	−0.375* (0.019)
Rest γ (Lotion)	0.428** (0.007)	−0.231 (0.156)
Rest γ (Emulsion)	0.612*** (<0.001)	−0.170 (0.300)
Rest γ (Cream)	0.459** (0.003)	−0.183 (0.265)
Avg. Acc (Lotion)	0.236 (0.148)	−0.246 (0.131)
Avg. Acc (Emulsion)	0.271 (0.095)	−0.277 (0.088)
Avg. Acc (Cream)	0.148 (0.369)	−0.215 (0.189)

n = 39; ( ), p value; *p < 0.05; **p < 0.01; ***p < 0.001

change of HRV. These results suggest that a more regular motion (smaller ApEn) and/or an increased duration of slow motions (lower Rest γ) during FSC may suppress the activity of the sympathetic nerve system, and more regular motion (smaller ApEn) during FSC may stimulate the activity of parasympathetic nerve system independently of the intensity of motion.

Discussion

In this study, we have proposed the usefulness of ApEn and Rest γ as quantitative parameters for evaluating FSC behavior. When using the lotion to the emulsion, the E group had a reduced ApEn compared to the NE group. Other two parameters did not show significant change between items. ApEn has been applied in the field of not only neurology [37] and endocrinology [38], but also motion analysis [39]. A lower ApEn indicates a more regular behavior, while higher ApEn values indicate more complex and unpredictable one [32, 40]. In this study, the E group has more regular behaviors than the NE group when using the emulsion. Alkjær et al. demonstrated a higher ApEn of the ankle joint angle when walking in high heels compared to walking barefoot, suggesting a variable adjusting strategy of the nervous system to control the ankle joint [41]. In the context of FSC, differences in the physical property of the emulsion or skin may influence the hand motion; it is certainly known that changes in the physical properties of the object affect the hand motion [42, 43]. However, factors affecting hand motion are more complex due to the context such as purpose [44] and prior knowledge [45]. We must consider further in detail.

Moreover, the E group has a lower Rest γ than the NE group. Rest γ is a universal parameter of a kind of power of law. Nakamura et al. demonstrate the same value for the life activity of healthy humans and mice [15, 34]. The averaged Rest γ value (emulsion) of the E group and NE group is − 0.834 ± 0.181 and − 0.975 ± 0.128, respectively (p = 0.012). The Rest γ of the NE group is similar to the value, 1.0, of the life activity of healthy people and mice [34, 35]. It is possible that the motion of the NE group is similar to an unconstrained motion without defect and consciousness. The E group indicates that the duration distribution of the slow motion increases; this may reflect constrained consciousness such as concentration and enjoyment of touching.

Furthermore, we have demonstrated that hand motion during FSC may influence ANS activity. There are some reports demonstrating that FSC provides a relaxing effect as a result of the stimulation of the parasympathetic nerve of the heart [3, 5, 7]. It is interesting that the effects of FSC on ANS activity are different in both groups. It is suggested that FSC of the E group has an inhibitory effect on the sympathetic nerve system (lower ccv(LF/HF)) and that FSC of the NE group has an inhibitory effect on the parasympathetic nerve system (lower ccv (HF)). In this study, the NE group may have trouble carrying out the routine and/or feel stressed when using items during daily FSC. In fact, Okada also suggested that the sympathetic nerve system is stimulated by self-FSC in the case of females with negative attitudes towards FSC [3]. These points require further study.

Interestingly, ApEn and Rest γ during FSC correlated with the change in ANS activity. High ApEn correlated with an increase in sympathetic nerve system activity and a decrease in parasympathetic nerve system activity. These data suggest that more regular (lower ApEn) motion and longer duration of slow motion (lower Rest γ) may lower the balance of ANS activity (sympathetic/parasympathetic

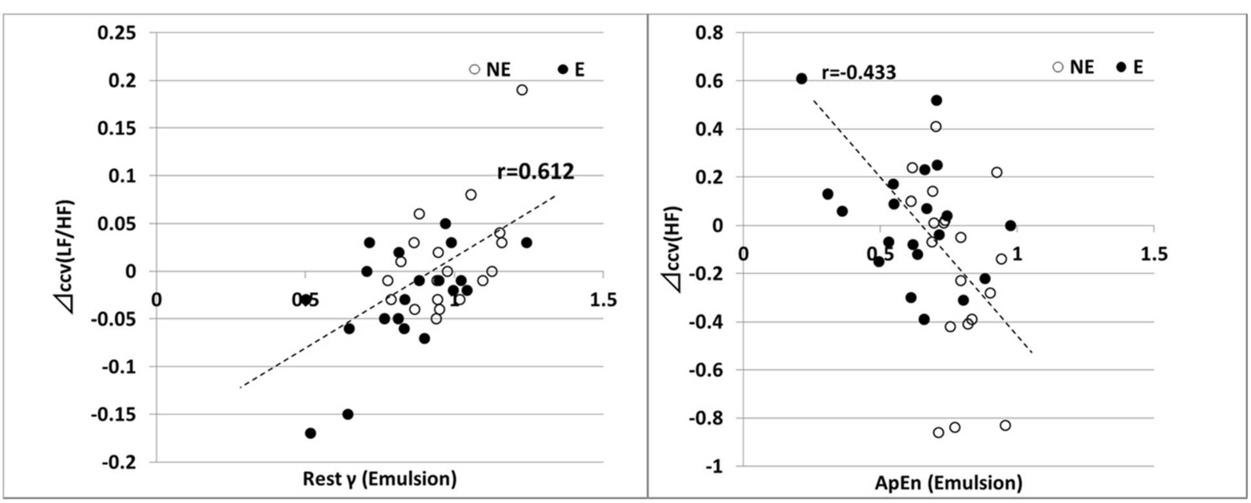

Fig. 5 Rest ϒ and ApEn correlates with the change of HRV by FSC (n = 39). E, enjoyment group (n = 20); NE, non-enjoyment group (n = 19)

nerve system activity). In general, exercise greatly affects the activity of sympathetic nerve system, but it is also known that static stretching activates the parasympathetic nerve system [46, 47]. In this study, the relationship between the acceleration of hand motion and the change of ANS activity is not confirmed, suggesting quality of hand motion but not the intensity of one may affect the balance of ANS activity in the case of FSC. FSC behavior consists of various movement units such as application, tapping, massage, and hand press. In the future, the relationship between each action and ApEn and Rest γ should be examined in detail. It will lead to constitutive understanding of FSC behavior. Feed-back system to user by monitoring ApEn and Rest γ of hand motion during FSC may bring to expand psychological potential for the balance of ANS activity in future.

Conclusion

ApEn and Rest γ are useful parameters for evaluating quality of hand motions during FSC.

Abbreviations

FSC: Facial skin care; E group: Enjoyment group; NE group: Non-enjoyment group; HRV: The heart rate variability; Avg. ACC: The averaged acceleration; ApEn: Approximate entropy; ANS: Autonomic nerve system; HF: High frequency; LF: Low frequency; ANOVA: Analysis of variance

Acknowledgements

The authors wish to express sincere gratitude to Ms. Akiko Iwabuchi, Kao Corporation, for sorting data.

Authors' contributions

All authors were involved in the conception of the study and design of the work. RT made the program for calculating ApEn and Rest γ. KU provided professional mathematical skill and technical advises. SS and MN were involved in the data collection and data analysis. All authors were involved in the interpretation of the analyzed data. SS was involved in initial drafting of the manuscript. All authors read and approved the final version of the manuscript to be published.

Funding

Kao Corporation raised all funds for this study

Availability of data and materials

The datasets during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was conducted according to the Helsinki Declaration. The methods and procedures of this study were reviewed and approved by the Review Board of the Kao Corporation (Tokyo, Japan) (No. 072-170808) and registered to the University Hospital Medical Information Network Center Registry of Japan (registration No. UMIN000029666) before enrollment of participants. Informed consent from all subjects was obtained prior to participation.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Skincare Products Research, Kao Corporation, 5-3-28, Kotobuki-cho, Odawara, Kanagawa 250-0002, Japan. [2]Graduate School of System Informatics, Kobe University, 1-1, Rokkodai, Nada 657-8501, Japan. [3]Present address: Core Device Development Sec., Service Development HQ, R&D Dept., Dwango Co., Ltd., Kabukiza Tower, 4-12-14 Ginza, Chuo-ku, Tokyo 104-0061, Japan. [4]Kansei Value Development Sensory Science Research, Kao Corporation, 5-3-28, Kotobuki-cho, Odawara, Kanagawa 250-0002, Japan.

Received: 28 November 2019 Accepted: 6 August 2020
Published online: 24 August 2020

References

1. Draelos ZD. The latest cosmeceutical approaches for anti-aging. J Cosmet Dermatol 2007; 6(SUPPL. 1): 2-6.doi; https://doi.org/10.1111/j.1473-2165.2007.00313.x.
2. Fowler JF Jr, Woolery-Lloyd H, Waldorf H, Saini R. Innovations in natural ingredients and their use in skin care. J Drugs Dermatol. 2010;9(6):s72–81 https://www.ncbi.nlm.nih.gov/pubmed/20626172. Accessed 25 Nov 2019.
3. Okada A. Effects of the facial feel of skin care products on heart rate variability and electroencephalogram. Japan Society of Physiological Anthropology. 1999;4(3):41–7. https://doi.org/10.20718/jjpa.4.3_147.
4. Hatayama T, Kitamura S, Tamura C, Nagano M, Ohnuki K. The facial massage reduced anxiety and negative mood status, and increased sympathetic nervous activity. Biomed Res (Japan) 2008; 29(6): 317-320. doi; https://doi.org/10.2220/biomedres.29.317.
5. Nozawa A, Takei Y. Comparative discussion on psychophysiological effect of self-administered facial massage by treatment method. IEEJ Trans Electron Inf Syst. 2012;132(5):706–12. https://doi.org/10.1541/ieejeiss.132.706.
6. Kohno Y, Koizumi Y, Sakai K, Kyuji K, Okayama M, Sakai K, Tsubomoto T, Hashimoto S, Kitamoto H. Physiological and psychological effects of tactile care in postmenopausal women (in Japanese). Japanese journal of nursing research. 2013;36(4):29–37. https://doi.org/10.15065/jjsnr.20130508004.
7. Suga K, Watanabe Y, Iwase S, Nishimura N, Shimizu Y, Iwase C. Basic study on the prefrontal cortex tissue oxygen level and autonomic nerve response produced by elder women performing their own facial care (in Japanese). Japanese Journal of Nursing Art and Science. 2015;14(2):137–45. https://doi.org/10.18892/jsnas.14.2_137.
8. Iida I, Noro K. An analysis of the reduction of elasticity on the ageing of human skin and the recovering effect of a facial massage. Ergonomics. 1995;38(9):1921–31. https://doi.org/10.1080/00140139508925240.
9. Nishimura H, Okuda I, Kunizawa N, Inoue T, Nakajima Y, Amano S. Analysis of morphological changes after facial massage by a novel approach using three-dimensional computed tomography. Skin Res Technol. 2017;23(3):369–75. https://doi.org/10.1111/srt.12345.
10. Pincus S. Approximate entropy (ApEn) as a complexity measure. Chaos. 1995;5(1):110–7. https://doi.org/10.1063/1.166092.
11. Nakamura T, Kim J, Sasaki T, Yamamoto Y, Takei K, Taneichi S: Intermittent locomotor dynamics and its transitions in bipolar disorder. 2013. International Conference on Noise and Fluctuations (ICNF), 13710888 doi; 10.1109/ICNF.2013.6578924.
12. Pincus SM, Goldberger AL. Physiological time-series analysis: what does regularity quantify? AM J PHYSIOL HEART CIRC PHYSIOL 1994; 266(4 35-4): H1643-H1656. https://www.ncbi.nlm.nih.gov/pubmed/8184944. Accessed 25 Nov 2019.
13. Pincus SM, Cummins TR, Haddad GG. Heart rate control in normal and aborted-SIDS infants. AM J PHYSIOL REGUL INTEGR COMP PHYSIOL. 1993; 264(3 33-3):R638–46 https://www.ncbi.nlm.nih.gov/pubmed/8457020. Accessed 25 Nov 2019.
14. Arif M, Ohtaki Y, Ishihara T, Inooka H: Walking gait stability in young and elderly people and improvement of walking stability using optimal cadence. Proceedings of 2002 International Symposium on Micromechatronics and Human Science: 245-251. doi; 10.1109/MHS.2002.1058042.
15. Nakamura T, Kiyono K, Yoshiuchi K, Nakahara R, Struzik ZR, Yamamoto Y. Universal scaling law in human behavioral organization. Phys Rev Lett. 2007; 99:13. https://doi.org/10.1103/PhysRevLett.99.138103.
16. Wang LH, Lin HT, Lo KC, Hsieh YC, Su FC. Comparison of segmental linear and angular momentum transfers in two-handed backhand stroke stances for different skill level tennis players. J Sci Med Sport. 2010;13(4):452–9. https://doi.org/10.1016/j.jsams.2009.06.002.
17. Fedorcik GG, Queen RM, Abbey AN, Moorman CT, Ruch DS. Differences in wrist mechanics during the golf swing based on golf handicap. J Sci Med Sport. 2012;15(3):250–4. https://doi.org/10.1016/j.jsams.2011.10.006.

18. Farana R, Jandacka D, Irwin G. Influence of different hand positions on impact forces and elbow loading during the round off in gymnastics: a case study. Sci Gymnastics J. 2013;5(2):5–14. https://doi.org/10.1080/02640414.2016.1158414.
19. Goebl W, Palmer C. Temporal control and hand movement efficiency in skilled music performance. PLoS ONE. 2013;8:1. https://doi.org/10.1371/journal.pone.0050901.
20. Terada K, Miyahara H, Kubo Y. An experiment of quantitative evaluation of Awa Odori dance. J Inst Image Electron Eng Jpn. 2005;34(3):220–7. https://doi.org/10.11371/iieej.34.220.
21. Sayers BM. Analysis of heart rate variability. Ergonomics. 1973;16(1):17–32. https://doi.org/10.1080/00140137308924479.
22. Akselrod S, Gordon D, Madwed JB, Snidman NC, Shannon DC, Cohen RJ. Hemodynamic regulation: investigation by spectral analysis. The American journal of physiology. 1985;249(4 Pt 2):H867–75 https://www.ncbi.nlm.nih.gov/pubmed/4051021. Accessed 25 Nov 2019.
23. Pagani M, Lombardi F, Guzzetti S, Rimoldi O, Furlan R, Pizzinelli P, Sandrone G, Malfatto G, Dell'Orto S, Piccaluga E et al. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. Circulation research 1986; 59(2): 178-1193. doi; https://doi.org/10.1161/01.RES.59.2.178.
24. Thayer JF, Lane RD. A model of neurovisceral integration in emotion regulation and dysregulation. J Affective Disord 2000; 61(3): 201-216.doi; 10.1016/S0165-0327(00)00338-4.
25. Porges SW. The polyvagal theory: phylogenetic substrates of a social nervous system. Int J Psychophysiol 2001; 42(2): 123-146.doi; https://doi.org/10.1016/S0167-8760(01)00162-3.
26. Appelhans BM, Luecken LJ. Heart rate variability as an index of regulated emotional responding. Rev Gen Psychol 2006; 10(3): 229-240.doi; https://doi.org/10.1037/1089-2680.10.3.229.
27. Hideaki W, Tatsuya H, Shogo M, Naruto Y, Hideaki T, Yoichi M, Yoshihiro O, Kazuo U, Hidenori T. Effect of 100 Hz electroacupuncture on salivary immunoglobulin A and the autonomic nervous system. Acupuncture in medicine : journal of the British Medical Acupuncture Society 2015; 33(6): 451-456. doi; https://doi.org/10.1136/acupmed-2015-010784.
28. Hasegawa M, Hayano A, Kawaguchi A, Yamanaka R. Assessment of autonomic nervous system function in nursing students using an autonomic reflex orthostatic test by heart rate spectral analysis. Biomedical reports. 2015;3(6):831–4. https://doi.org/10.3892/br.2015.512.
29. Jia T, Ogawa Y, Miura M, Ito O, Kohzuki M. Music attenuated a decrease in parasympathetic nervous system activity after exercise. PLoS ONE 2016; 11(2): e0148648. doi; https://doi.org/10.1371/journal.pone.0148648.
30. Kobayashi Y, Fujikawa T, Kobayashi H, Sumida K, Suzuki S, Kagimoto M, Okuyama Y, Ehara Y, Katsumata M, Fujita M, et al. Relationship between arterial stiffness and blood pressure drop during the sit-to-stand test in patients with diabetes mellitus. Journal of atherosclerosis and thrombosis. 2017;24(2):147–56. https://doi.org/10.5551/jat.34645.
31. Waki H, Suzuki T, Tanaka Y, Tamai H, Minakawa Y, Miyazaki S, Yoshida N, Uebaba K, Imai K, Hisajima T. Effects of electroacupuncture to the trigeminal nerve area on the autonomic nervous system and cerebral blood flow in the prefrontal cortex. Acupuncture in medicine : journal of the British Medical Acupuncture Society. 2017;35(5):339–44. https://doi.org/10.1136/acupmed-2016-011247.
32. Pincus SM. Approximate entropy as a measure of system complexity. Proc Natl Acad Sci U S A. 1991;88(6):2297–301. https://doi.org/10.1073/pnas.88.6.2297.
33. Pincus SM. Assessing serial irregularity and its implications for health. In: *Annals of the New York Academy of Sciences.* vol. 954: New York Academy of Sciences; 2001: 245-267. https://www.ncbi.nlm.nih.gov/pubmed/11797860 Accessed 25 Nov 2019.
34. Nakamura T, Takumi T, Takano A, Aoyagi N, Yoshiuchi K, Struzik ZR, Yamamoto Y. Of mice and men - universality and breakdown of behavioral organization. PLoS ONE 2008; 3(4).doi; 10.1371/journal.pone.0002050.
35. Sano W, Nakamura T, Yoshiuchi K, Kitajima T, Tsuchiya A, Esaki Y, Yamamoto Y, Iwata N. Enhanced persistency of resting and active periods of locomotor activity in schizophrenia. PLoS ONE 2012; 7(8).doi; 10.1371/journal.pone.0043539.
36. Hayano J, Sakakibara Y, Yamada A, Yamada M, Mukai S, Fujinami T, Yokoyama K, Watanabe Y, Takata K. Accuracy of assessment of cardiac vagal tone by heart rate variability in normal subjects. The American journal of cardiology 1991; 67(2): 199-204. https://www.ncbi.nlm.nih.gov/pubmed/1987723 Accessed 25 Nov 2019.
37. Pincus SM, Viscarello RR. Approximate entropy: a regularity measure for fetal heart rate analysis. Obstet Gynecol 1992; 79(2): 249-255. https://www.ncbi.nlm.nih.gov/pubmed/1731294 Accessed 25 Nov 2019.
38. Pincus SM, Mulligan T, Iranmanesh A, Gheorghiu S, Godschalk M, Veldhuis JD. Older males secrete luteinizing hormone and testosterone more irregularly, and jointly more asynchronously, than younger males. Proc Natl Acad Sci U S A. 1996;93(24):14100–5. https://doi.org/10.1073/pnas.93.24.14100.
39. Cysarz D, Lange S, Matthiessen PF, Van Leeuwen P. Regular heartbeat dynamics are associated with cardiac health. AM J PHYSIOL REGUL INTEGR COMP PHYSIOL 2007; 292(1): R368-R372. doi; https://doi.org/10.1152/ajpregu.00161.2006.
40. Stergiou N, Decker LM. Human movement variability, nonlinear dynamics, and pathology: is there a connection? Hum Mov Sci. 2011;30(5):869–88. https://doi.org/10.1016/j.humov.2011.06.002.
41. Alkjær T, Raffalt P, Petersen NC, Simonsen EB. Movement behavior of high-heeled walking: how does the nervous system control the ankle joint during an unstable walking condition? PLoS ONE. 2012;7:5. https://doi.org/10.1371/journal.pone.0037390.
42. Meftah EM, Belingard L, Chapman CE. Relative effects of the spatial and temporal characteristics of scanned surfaces on human perception of tactile roughness using passive touch. Exp Brain Res. 2000;132(3):351–61. https://doi.org/10.1007/s002210000348.
43. Mueller S, Martin S, Schwarz M, Grunwald M. Temporal modulations of contact force during haptic surface exploration. PLoS ONE. 2016;11:4. https://doi.org/10.1371/journal.pone.0152897.
44. Lederman SJ, Klatzky RL. Hand movements: a window into haptic object recognition. Cogn Psych. 1987;19(3):342–68. https://doi.org/10.1016/0010-0285(87)90008-9.
45. Kaim L, Drewing K. Exploratory strategies in haptic softness discrimination are tuned to achieve high levels of task performance. IEEE Trans Haptic. 2011;4(4):242–52. https://doi.org/10.1109/TOH.2011.19.
46. Farinatti PTV, Brandão C, Soares PPS, Duarte AFA. Acute effects of stretching exercise on the heart rate variability in subjects with low flexibility levels. J Strength Cond Res. 2011;25(6):1579–85. https://doi.org/10.1519/JSC.0b013e3181e06ce1.
47. Sakai Y, Umeno K, Ogishima H, Tsuji M, Kamijo M. Effects of static stretching of the triceps surae muscle driven by motor control on relaxation: Subjective comfort and autonomic nervous function after static stretching. Rigakuryoho Kagaku. 2014;29(3):383–7. https://doi.org/10.1589/rika.29.383.

Publisher's Note