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Biosignal-based Relaxation Evaluation of Head-care Robot*

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Abstract—**Such popular head care procedures as shampooing and scalp massages provide physical and mental relaxation. However, they place a big burden such as chapped hands on beauticians and other practitioners. Based on our robot hand technology, we have been developing a head care robot. In this paper, we quantitatively evaluated its relaxation effect using the following biosignals: accelerated plethymography (SDNN, HF/TP, LF/HF), heart rate (HR), blood pressure, salivary amylase (sAA) and peripheral skin temperature (PST). We compared the relaxation of our developed head care robot with the head care provided by nurses. In our experimental result with 54 subjects, the activity of the autonomic nerve system changed before and after head care procedures performed by both a human nurse and our proposed robot. Especially, in the proposed robot, we confirmed significant differences with the procedure performed by our proposed head care robot in five indexes: HF/TP, LF/HF, HR, sAA, and PST. The activity of the sympathetic nerve system decreased, because the values of its indexes significantly decreased: LF/HF, HR, and sAA. On the other hand, the activity of the parasympathetic nerve system increased, because of the increase of its indexes value: HF/TP and PST. Our developed head care robot provided satisfactory relaxation in just five minutes of use.**

I. Introduction

People want both physical and psychological relaxation. Head-care and hair washing are essential ways not only to become clean but also to relax [1]. Head-cares provides such benefits as a clean scalp, clean hair, increased blood flow, improved scalp function, and stimulated mental states. Head-care is commonly conducted in barber shops, beauty salons, and care and massaging facilities. To wash hair more comfortably and effectively, many studies have focused on shampooing methods. Others examined physiological and psychological responses in a standardized procedure [2, 3], suggesting the benefits of warming, circulation-enhancing, and relaxation.

On the other hand, providing proper head care greatly burdens its practitioners, causing back pain and chapped hands. In care facilities, due to burden and business, the frequency of head care is lower than expected [4].

An automatic shampooing machine, which only uses a water stream and has already been put to practical use in some barber shops and hair salons [5][6], has reduced practitioner burden. However, it often gives people a tickling or unpleasant sensation and consumes about 50 liters of water in one use.

Based on our robotics technology, we have been developing an original head-care robot to make users more comfortable [7]. Our head-care robot can wash the scalp with its fingers and provide a rich lather of shampoo in addition to a stream of water. This allows the head-care robot to provide feelings of much relaxation, to wash hair cleanly [8], and to reduce water consumption to about 15 liters per shampoo. In current stressful society, the head-care robot has possibility to propose comfort and relaxation effect.

The purpose and originality of this paper is to show quantitatively the relaxation effect produced by a head care robot. In quantitative relaxation evaluations, we measured the biosignals including autonomic nerve system data from sympathetic and parasympathetic nerve systems.

II. Head-care Robot to Shampooing and Massaging

Our head-care robot gently touches the head and thoroughly washes it with a rich lather of shampoo. Fig. 1 shows our head-care robot and its dimensions: W 810×H 1045×D 723 mm and weighing 100 kg. It performed the following head care sequence: pre-washing, shampooing, rinsing, conditioning, massaging, washing, and drying. It lathers the shampoo well, massages the scalp with its fingers, and produces clean and comfortable feelings like a beautician.

As shown in Fig. 1, our head-care robot consists of two main parts: right and left swing arm units that massage the front and top regions of the head and a rear unit that cleans its back. The swing arm unit is composed of a pressing arm and an end effecter that is attached at its tip. The end effecter part, which touches and washes the scalp and the hair, is composed of eight human-like elastic fingers.

In our first prototype that was called Proto 0, the swing arm unit has two degrees of freedom (DoF): swinging and pressing movements [7]. Based on test comments, users claimed difficulty feeling satisfactory relaxation because repetitive combination of swinging and pressing movements was monotonous. In our latest model called Proto 1 that addressed Proto 0's problem, we added an extension movement of the swing arm [8] (See Fig. 2). In Proto 1, the

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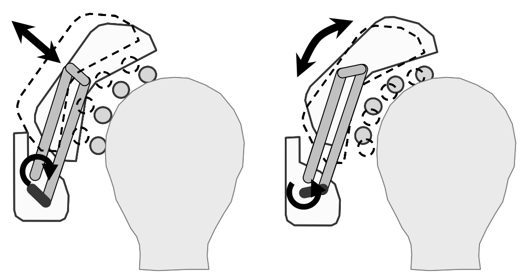
Fig.. 1 Apparatus of head care robot



(a) pressing (b) extension

Fig. 2 Pressing and extension movement of swing arm unit

end effecter applies 1~2 kgf to the head using virtual compliance control and its range of motion (ROM) covers an average female head.

III. Biosignals Measurement Experiment

A. Objective

Our objective is to quantitatively show the effectiveness of our developed head care robot using the biosignals of the autonomic nerve system from the viewpoints of relaxation, comfort, and stress. We compared the relaxation effect produced by Proto 1, our newly developed robot, with our previous robot, Proto 0, and a nurse's hands.

B. Methodology

Subjects: All subjects provided written informed consent, and our experiment's protocol was approved by the Ethics Committee at the Osaka University Division of Health Sciences. Our subjects were comprised of 54 healthy people, 27 males and 27 females with the following characteristics: age: 25.2±5.7 years, height: 1.65±0.09 m, and weight: 56.7±8.1 kg. Hairstyles were targeted from short to medium length, less than 400 mm. The average hair length was 263±137 mm. The subjects received the following instructions to obtain stable biosignals: 1) don't shampoo the day before experiment, 2) avoid alcohol, caffeine, and excessive exercise the day before experiment and get enough sleep, 3) avoid hair spray or applying anything else to the hair, including nail polish to your nails, and 4) don't eat three hours before the experiment. Since the estradiol cycle affects the autonomic nervous system, we also asked whether the female subjects were menstruating on the experiment day [9].

Protocol: The subjects were randomly divided into three groups: Group 1) nurse, Group 2) Proto 0, and Group 3) Proto 1. Each group was comprised of 18 subjects. The subjects in Group 1 were shampooed by nurses with head care experience at hospitals or care facilities; those in Group 2 were shampooed by Proto 0 (as described in Section 2), and those in Group 3 were shampooed by Proto 1 (as described in Section 2). In Group 1, the nurses were not allowed to communicate with the subjects, because neither robot was able to communicate with the subjects. Nurse and robots were provided the same amount of shampoo (10 ml per person) and shampoo time (one-minute rinse, two-minute wash, and a 1.5-minute rinse).

We measured the biosignals of the autonomic nerve system to show the effect of being shampooed by the nurse and the two robots. The signals from the subjects were measured twice with their eyes closed as follows: lying in a supine position after resting on a bed for 10 min, which was called the *rest before shampooing (RBS) condition*, and lying in a supine position after having their hair dried and resting on a bed for 10 min, which was called the *rest after shampooing (RAS) condition*.

Heart rate variability (HRV) [10, 11], blood pressure (BP) [12], heart rate (HR) [12][13], salivary amylase activity (sAA) [14], and peripheral skin temperature (PST) [15] were measured as physiological responses. Subjects wore a wrist digital manometer (EW-BW30, Panasonic Co., Japan) on their right wrist, an accelerated plethymography (SA-3000P, Tokyo Iken Co., Japan) on their left index finger, and a dermatherm sensor (DS101, Tateyama Kagaku Industry Co.) between their left middle finger and left thumb. sAA was measured by an enzyme analysis machine (CM-2.1, NIPRO, Japan).

Beat-to-beat heart rate variability (HRV) is a measure of autonomic nervous system activity, which can be quantified using frequency domain analysis. HRV, which was measured for three minutes, analyzed all of the following: the Standard Deviation of the RR Interval (SDNN: the standard deviation of NN intervals. The term NN is used in place of RR to emphasize the fact that the processed beats are normal beats.) as an index of the autonomic nerve activity, the ratio of power of the high frequency (HF: 0.15-0.4 Hz) to that of total spectrum in the variability signal (TP, a measure of overall autonomic activity), HF/TP for the parasympathetic nerve activity, and the ratio of the power of the low frequency (LF: 0.04-0.15 Hz) for the sympathetic and parasympathetic nerve activity to that of high frequency (LF/HF) as a balance of the autonomic nerve system [16].

SDNN, HF/TP, and PST are evaluation indexes that show the activity of the parasympathetic nerves. LF/HF, SBP, DBP, HR, and sAA are evaluation indexes that show the activity of sympathetic nerves. Therefore, the SDNN, HF/TP, and PST values increase when eustress, which measures healthy stress, is applied and then subjects become comfortable. The LF/HF, SBP, DBP, HR, and sAA values decreased when eustress was applied to the subjects.

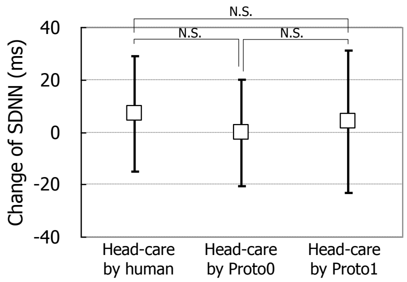


Fig.. 4 Change of SDNN by head care procedure

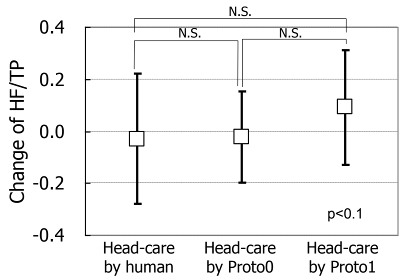


Fig.. 5 Change of HF/TP by head care procedure

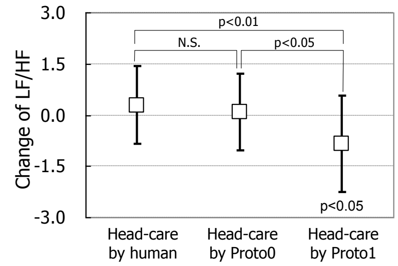


Fig.. 6 Change of LF/HF by head care procedure

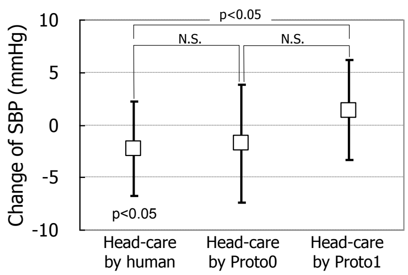


Fig.. 7 Change of SBP by head care procedure

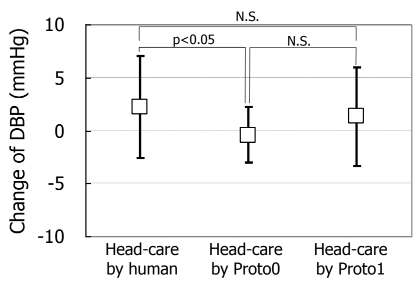


Fig.. 8 Change of DBP by head care procedure

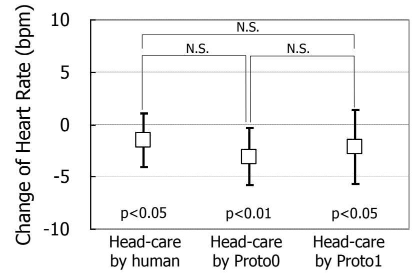


Fig.. 9 Change of heart rate by head care procedure

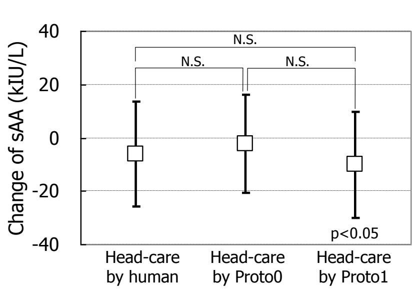


Fig.. 10 Change of sAA by head care procedure

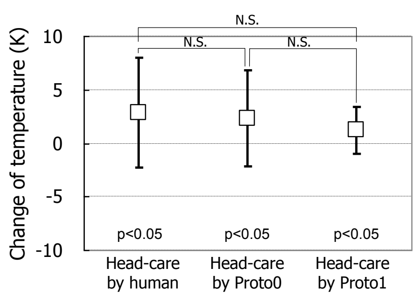


Fig.. 11 Change of peripheral skin temperature by head care procedure

Our experiment was done in a stable, 20.4±2.5C environment with 50±20% humidity.

Statistical analysis: Our data results, which are shown as mean value ± standard deviation, were analyzed statistically by the following two methods.

-- We compared the biosignal values in *RBS* and *RAS* to show the effectiveness of each procedure (nurse, Proto 0, and Proto 1) using Mann-Whitney U test.

-- The differences between the biosignal values in *RBS* and *RAS* were analyzed among all three procedures using Bonferroni post hoc tests to show the differences of shampooing procedures.

C. Result

Fig. 4 shows the change of SDNN when head care was conducted by the nurse, Proto 0, and Proto 1. It increased 6.9±22 ms by the nurse, decreased 0.4±20.4 ms by Proto 0, and increased 3.9±27.2 ms by Proto 1. A relaxation tendency was shown; however, no significant difference was confirmed in any condition.

Fig. 5 shows the change of HF/TP when head care was conducted by the nurse, Proto 0, and Proto 1. It decreased 0.03±0.25 by the nurse, decreased 0.02±0.18 by Proto 0, and increased 0.09±0.22 by Proto 1. HF/TP significantly increased by Proto 1's head care ($p<0.1$). Proto 1's relaxation effect was confirmed.

Fig. 6 shows the change of LF/HF when head care was conducted by the nurse, Proto 0, and Proto 1. LF/HF increased 0.28±1.1 by the nurse, increased 0.068±1.1 by Proto 0, and decreased 0.84±1.4 by Proto 1. LF/HF significantly decreased by Proto 1's head care ($p<0.05$). The relaxation effect of Proto 1 was confirmed. In addition, head care by Proto 1 was deemed more comfortable than that by the nurse ($p<0.01$) and Proto 0 ($p<0.05$).

Fig. 7 shows the change of SBP when head care was conducted by the nurse, Proto 0, and Proto 1. The SBP decreased 2.3±4.5 mmHg by the nurse, decreased 1.8±5.6 mm Hg by proto 0, and increased 1.4±4.8 mmHg by Proto 1. SBP was significantly decreased by human head care ($p<0.05$). In addition, head care by Proto 1 was more uncomfortable than that by the nurse ($p<0.05$). However, the change of SBP was only 2-3 mmHg.

Fig. 8 shows the change of DBP when head care was conducted by the nurse, Proto 0, and Proto 1. The DBP increased 2.2±4.8 mmHg by the nurse, decreased -0.4±2.6 mmHg by Proto 0, and increased 1.3±4.7 mmHg by Proto 1. No significant change was confirmed in any condition.

Fig. 9 shows the change of HR when head care was conducted by the nurse, Proto 0, and Proto 1. The HR decreased 1.5±2.6 bpm (beats per minute) by the nurse, decreased 3.1±2.7 bpm by Proto 0 and decreased 2.2±3.5 bpm by Proto 1. HR significantly decreased with the nurse's head-care ($p<0.05$), Proto 0's head care ($p<0.01$), and Proto 1's head care ($p<0.05$). We confirmed relaxation by head care. No significant difference among procedures was confirmed.

Fig. 10 shows the change of sAA when head care was conducted by the nurse, Proto 0, and Proto 1. sAA decreased 6.3±19 kIU/L by human, decreased 2.4±19 kIU/L by Proto 0, and decreased 10±20 kIU/L by Proto 1. sAA significantly decreased in Proto 1 head care ($p<0.05$). Relaxation using Proto 1 was shown. No significant difference among procedures was confirmed.

Fig. 11 shows the change of PST when head care was conducted by the nurse, Proto 0, and Proto 1. The PST increased 2.9±5.2 C by the nurse, increased 2.3±4.5 C by Proto 0, and increased 1.2±2.2 C by Proto 1. PST significantly increased in the nurse's head-care ($p<0.05$), Proto 0's head care ($p<0.05$), and Proto 1's head care ($p<0.05$). Relaxation in head care was shown. No significant difference among procedures was confirmed.

D. Discussion

The activity of the autonomic nerve system changed before and after the head care procedures. Significant differences were confirmed by the head care procedure of Proto 1 in five indexes: HF/TP, LF/HF, HR, sAA, and PST. The activity of the sympathetic nerve system decreased, because the value of the indexes of the sympathetic nerve system, LF/HF, HR, and sAA, significantly decreased. On the other hand, the activity of the parasympathetic nerve system increased, because the value of the sympathetic indexes, HF/TP and PST, significantly increased. Therefore, our newly developed Proto 1 produced more relaxation than the nurse and Proto 0 during a five-minute procedure.

According to our observation, half of the user became sleeping during the experiment (some users told that they were sleepy or they slept for washing/ massaging the scalp.).

Our Proto 1 head care robot created much relaxation in a few minutes. In shampooing by the nurse, Funaki et al. [2] reported the following findings: HR significantly decreased (about 5 bpm), SBP and SBP did not change, HF significantly increased, and LF/HF significantly decreased. Their result showed that good relaxation can be realized by head care by a human. Our head care result by nurses matched Funaki's HR result but the other indexes' results did not. This is because the shampooing time of Funaki's experiment, twenty minutes, exceeded our experiment.

IV. CONCLUSION

In this paper, we quantitatively evaluated the relaxation effect produced by a head care robot using such biosignals as accelerated plethymography, heart rate, blood pressure, salivary amylase, and peripheral skin temperature. In an experiment with the results of 54 subjects, we changed the activity of the autonomic nerve system before and after head care procedures. We also confirmed significant differences by the head care procedures of our proposed robot in five indexes: heart rate variability (HF/TP, LF/HF), heart rate, salivary amylase activity and peripheral skin temperature. The activity of the sympathetic nerve system decreased, because the value of the indexes of the sympathetic nerve system, LF/HF, heart rate, and salivary amylase activity, significantly decreased. On the other hand, the activity of the parasympathetic nerve system increased, due to the value of the following sympathetic indexes: HF/TP and peripheral skin temperature. Our developed head care robot provided satisfactory relaxation in a five-minute procedure.

In current stressful society, the comfort given by the head-care robot is important.

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