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Development of Textile Electrode for Electrocardiogram Measurement Based on Conductive Electrode Configuration

Hakyung Cho, Hosun Lim[1]*, Sangwoo Cho[2], and Jeong-Whan Lee[3]

Department of R&D, Lucis Co. Ltd., Seoul 04781, Korea
[1]*Department of Clothing & Textiles, Sookmyung Women's University, Seoul 04310, Korea*
[2]*Department of Sports Science, Hoseo University, Asan 31499, Korea*
[3]*Division of Biomedical Engineering, Konkuk University, Chungju 27478, Korea*
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Abstract: Recently, the demands of the wearable systems and products for monitoring biosignal to manage the health are increased by the increasing interests for introducing an aging society and for the lifestyle of well-being. Global sports brands such as Adidas and Nike tried to enter into the market with the study about the wearable system for measuring the heart-rate, and lately global casual brand of Polo is going to introduce the market expansion with business implementations. However, the studies of textile materials for measuring an electrocardiogram have constantly conducted but the studies for correlation of an electrocardiogram measurement signal by electrode structure and type are insufficient. Therefore, this study developed 8 types of electro-thread by considering the condition of TM and covering based on the silver thread, and developed total 16 type electrodes by consisting two different size of electrode. By comparing and analyzing magnitudes of biosignal and noise according to electrode size when standing with applied the developed electrode into tight sports wears, we evaluated the effectiveness with electrocardiogram measurement electrode by its size. From this case, it derived the correlation of electrode for electrocardiogram measurement and design factors according to the final suitable electro-thread and the electrode size after analyzing signals and noises from standing and walking based on small size electrode that is dominant to measure signals.

Keywords: Electro-thread, Electrode component, Textile electrode, Electrocardiogram, Motion artifact

Introduction

Lately due to the demographic shift and the increased medical costs by aging population, the interests to measure unconscious noninvasive biosignal are rising any time and any places, and the demands for wearable systems as the one way for this issue are also increasing [1-3].

According to the increases of interests and demands for wearable health monitoring technology, the smart wears to measure biosignal are variously researched and approached mainly in Europe and USA [4-6]. Because the smart wear that has main material with textile is flexible and suited to human body with economic interface, textile electrode based on conductive textile for biosignal measurements has been developed and applied with various structures [7]. The studies for textile electrode applied to general textiles of electrode material, nickel plate, silver coating, and copper sputtering and the studies for various materials consisting of electrode to measure biosignal such as conductive ink and rubber conductive substance have conducted [8,9].

The study related to textile electrode for biosignal measurement was very active with business implementation of heart-rate measuring wears based on Adidas from 2000s, which is global sports brand, and lately to measure high quality biosignal, it is variously approached with not only electrode material but its pattern design and minimized motion artifact.

The study for biosignal measurements by scheme and configuration of electrode is progressing based on the study for measuring biosignal of electrode according to textile design of electro-thread [10-12] and on the study for design to improve adhesion into skin and design of 3D electrode [13]. Also, the study of biosignal measurement through electrode material and structure could apply different original threads even with limited its area, and so the study approached compositively on design of electrode size is insufficient. Therefore, this study designed and developed 8 types of electro-thread by considering conductivity and suitability on body so that analyzed signals by electro-threads. Furthermore, the developed electrode was manufactured by two different sizes and derived requirements for electrode design by the size. By generalizing, we finally analyzed and suggested the requirement of electro-thread and electrode size, which is suitable for electrocardiogram signal measurement, and the electrode components.

Experimental

To derive optimized factor of textile electrode for measuring electrocardiogram, this study considered previous researches having basic property of electrode and structure of textile electrode, and designed 8 types of electro-thread based on it. 8 types of electrodes for knitted fabric with the same structure were produced to evaluate electrode suitability to designed 8

*Corresponding author: lhs@sm.ac.kr

electro-threads, and total 16 types of electrode were designed and manufactured for electrocardiogram signal evaluation by electrode size with comprising two different sizes. The experiment on condition of standing and walking was conducted to estimate the developed electro-thread and the electrocardiogram signal measurement. First, we analyzed electrocardiogram signals according to electro-thread type and electrode size by measuring its signals with 16 electrodes in the condition of standing and presented the result. Second, based on the results derived previously, the electrocardiogram measurement at the time of walking was progressed to evaluate the effect of motion artifact for 8 types of electrode and the signal stability in walking by electrode property from electro-thread was also estimated. Finally, generalizing above two experimental results, we analyzed and suggested the requirement of electro-thread and electrode size, which is able to measure optimized electrocardiogram signal, and suitable electrode components in standing and walking.

Electrode Design

Electro-Thread

To analyze and suggest suitable electrode components for electrocardiogram measurement, the component of 8 electro-threads as following was designed and developed (Table 1, Figure 1). The polyester 75 denier was used as the core yarn, and one strand or two strands of 50 μm silver thread was structured as the covering. Considering friction with the skin and the accuracy of the signals, a total of 8 types of electro-thread were constructed according to the TM conditions of the silver thread and covering.

As shown in the Table 1, No. 1, 2, 3, and 4 designed the basic configuration with one strand of silver thread and No. 5, 6, 7, and 8 with two strands of silver thread. In the case of No. 1, 2, 5, and 6 were applied by silver thread with a condition of 700TM, No. 2 and 6 had covering with poly 30d upon silver thread by considering the sensitivity touched to the body, and No. 1 and 5 hadn't covering with poly 30d and were exposed to silver thread. No. 3, 4, 7, and 8 were applied by silver thread with a condition of 1300TM for more exposure towards its surface, and No. 3 and 7 had covering with poly 30d and mitigated feeling of irritation by electrode on the human body likely No. 2 and 6. No. 1, 3, 5, and 7 were produced as electro-thread exposed to silver thread without covering with poly 30d, and No. 2, 4, 6, and 8 were produced as electro-thread having poly 30d covering. Finally the specifications of designed 8 types of electro-thread are as following (Table 1).

Knitted Fabric

To analyze the efficiency of electrode by electro-thread types and the suitability of signal extraction by electrode sizes, the plain knitted fabric having the same structure was manufactured by using Lab. knitter GTK-578 knitting machine applied 8 types of electro-thread and its result show in following picture (Figure 2). 8 types of electro-thread were knitted by 8 samples as followed, and individual knitted

Table 1. Specifications of designed electro-thread 8 types

No.	Spec.
1	Polyester 75d+Silver thread 50 μm×1 (700TM)
2	Polyester 75d+Silver thread 50 μm×1 (700TM)+poly 30d
3	Polyester 75d+Silver thread 50 μm×1 (1300TM)
4	Polyester 75d+Silver thread 50 μm×1 (1300TM)+poly 30d
5	Polyester 75d+Silver thread 50 μm×2 (700TM)
6	Polyester 75d+Silver thread 50 μm×2 (700TM)+poly 30d
7	Polyester 75d+Silver thread 50 μm×2 (1300TM)
8	Polyester 75d+Silver thread 50 μm×2 (1300TM)+poly 30

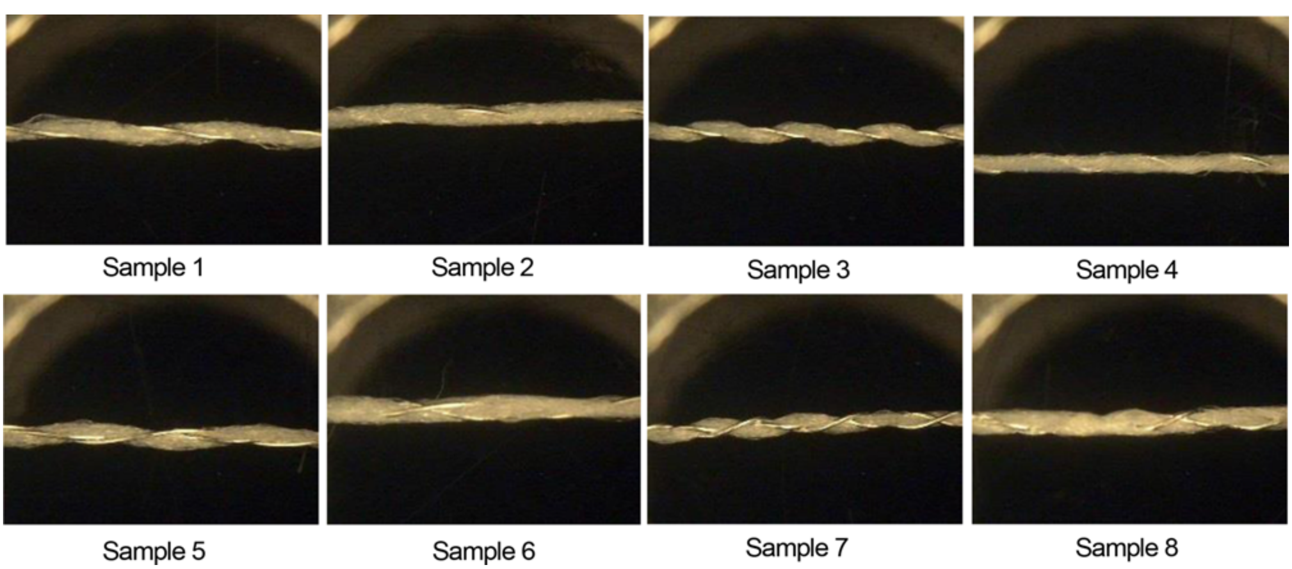


Figure 1. Picture of electro-thread 8 types by image microscope.

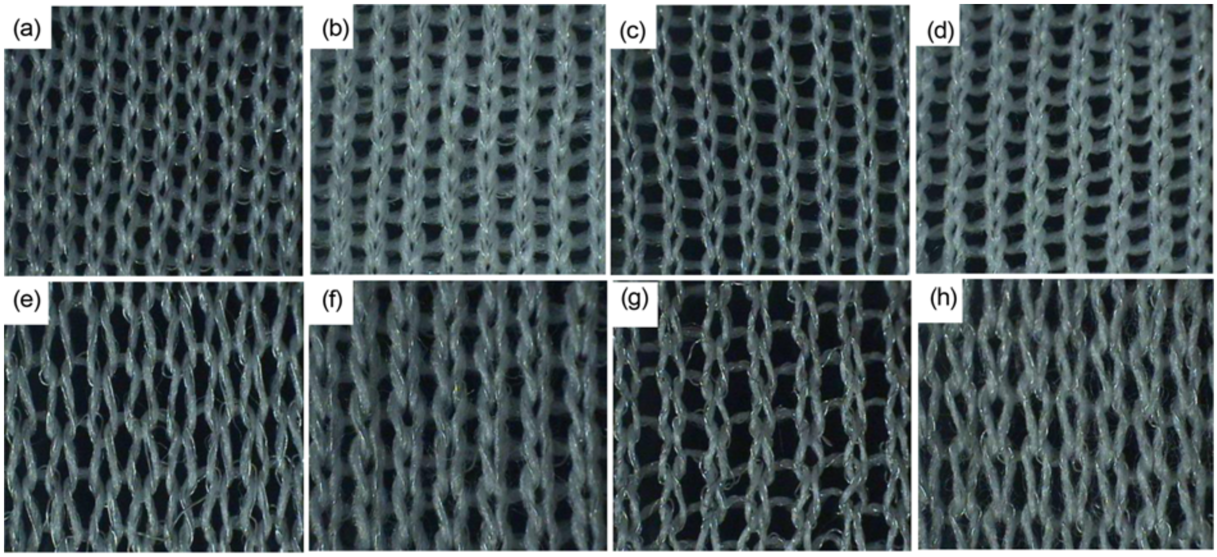


Figure 2. Optical microscope photos of knit samples (600× magnification); (a) knit sample 1, (b) knit sample 2, (c) knit sample 3, (d) knit sample 4, (e) knit sample 5, (f) knit sample 6, (g) knit sample 7, and (h) knit sample 8.

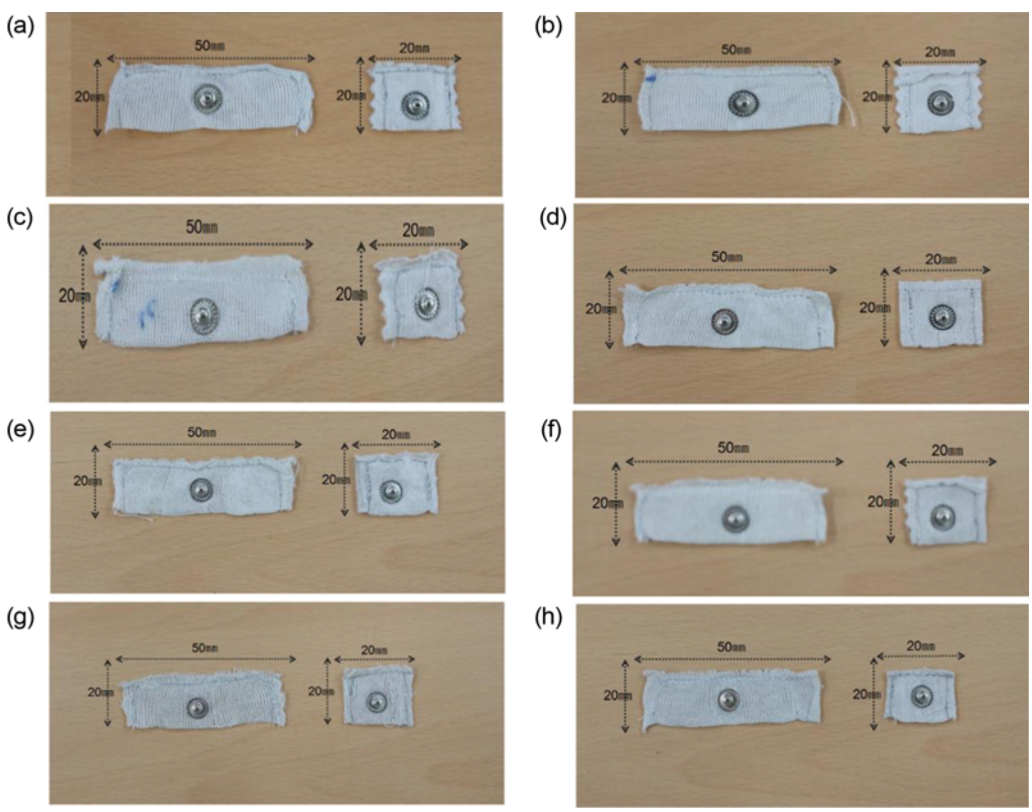


Figure 3. 16 types of electrode samples by small (2×2 cm) and large (5×2 cm) size; (a) electrode sample 1, (b) electrode sample 2, (c) electrode sample 3, (d) electrode sample 4, (e) electrode sample 5, (f) electrode sample 6, (g) electrode sample 7, and (h) electrode sample 8.

fabric was made by two sizes of 5×2 cm and 2×2 cm and total 16 types of samples were used for the experiment.

Electrode

For the evaluation in the same condition, knitted 16 types were designed to apply into the same wears (Figure 3). The conductive knit was made up two layers. Snap button was attached to one layer of the conductive knit and it was consisted to electrify through signal line when it was faced

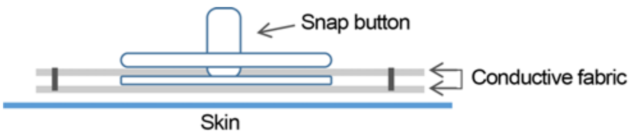


Figure 4. Electrode configuration for the snap.

to the garments. In addition, to prevent a direct touch of snap on the skin, the other layer was overlapped under the one lay having snap button (Figure 4). The conductive knits with two layers was finished by sewing with polyester thread.

Human Wearing Tests

Experimental Sequence and Participants

To evaluate the electrode property, the subjects of 5 males were selected as followed with the range of standard BMI index, and the detailed features of subjects are shown in Table 2. In this experiment, male subjects were selected to measure electrocardiogram signal by considering body contour and shape, and the evaluation of electrode through female subjects were excluded in this study.

To analyze electrocardiogram signal by electro-thread property and electrode size, five subjects participated in this experiment were involved to measure electrocardiogram for 60 sec after stabilizing during 180 sec in the resting condition, and this measurement was repeated three times with back to the resting condition. The results according to electrocardiogram signal with electro-thread property and electrode size were suggested after analyzing the average. Also, based on the previous experimental results, 8 types of electrode having relatively good signal quality were executed to estimate electrocardiogram signal when walking and finally it derived electro-thread and electrode suitable for motion artifact followed by indicating its requirements. All subjects were controlled to walk at the speed of 4 km/h on the treadmill for evaluating electrocardiogram signal measurement when walking, and the signal amplitude signal and SNR were

Table 2. Subject characteristics

Subject	Age	Height (cm)	Weight (kg)	BMI
1	26	175	69.5	22.69
2	26	174	68.4	22.59
3	26	177	72.0	22.98
4	24	171	66.2	22.64
5	24	178	70.0	22.09

Table 3. Experiment protocol

180 sec	60 sec	180 sec
Rest	Measurement	Recovery
← Standing : repeated three times →		
← 4 km/h Walking : repeated three times →		

compared and analyzed. In generalizing prior evaluations, the component of original thread and the size of electrode for optimized electrocardiogram measurement were finally derived.

Configuration of Experimental Garments

The experimental garments used in this test were consisted of polyurethane 92 % and lycra 8 % fabrics as the type of sleeveless tight sports t-shirt (Figure 5). The attachment location of textile electrode for the property evaluation applied in this experiment was selected to the lower part both sides of chest having good position for superior adhesive

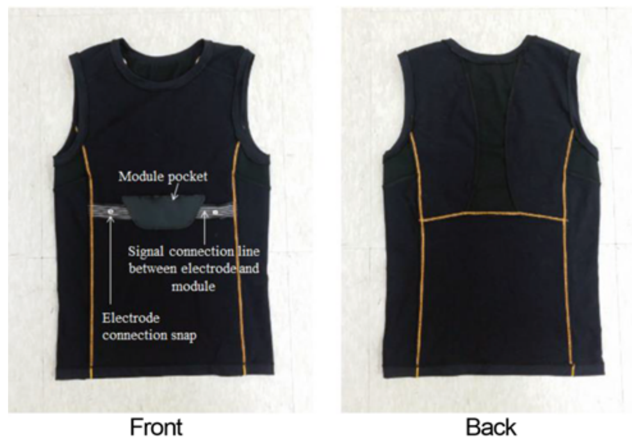


Figure 5. Configuration of experimental garments.

Figure 6. Appearance of electrode connection in experimental garments.

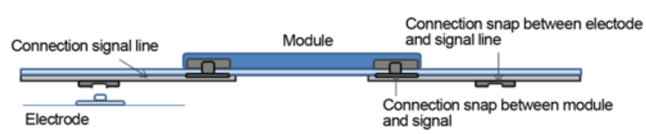


Figure 7. Signal line and electrode connection part of experimental garments.

strength on the body and the textile electrodes were attached to the inside of the clothes.

Furthermore, to give the same condition for measuring electrocardiogram signal of each electrode, tight sports t-shirt that is able to attach and detach electrode were manufactured and used to measure electrocardiogram signal within the same wears through electrode removal after wearing.

The module of electrocardiogram measurement was configured to be located in the middle of chest by considering its attachment location, and total 16 types of electrode developed in this experiment were able to attach and detach by putting snap button on the signal line that is connected to the module (Figures 6 and 7). The pressure around electrode was set as the pressure of 40 gf/cm^2 within wears not to have any inconveniences by adhering to the body.

Measuring Device

The device used in this experiment were BN-RSPEC BioNomadix RSP & ECG that measure electrocardiogram and transmit its data wireless, and the filter was set in frequency band to R-peak detection and Notch Filter was set to 60 Hz (Table 4). Measured electrocardiogram signals were visualized and showed through Acqknowledge 4.0 (Figure 8).

Table 4. Specification of BN-RSPEC device

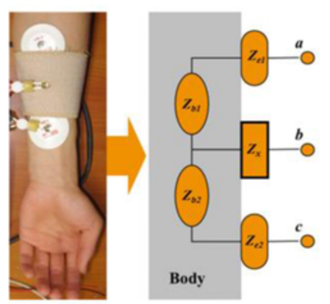
BioNomadix pair	BN-RSPEC
Signal type:	RSP plus ECG
Bandlimits max:	0.05 Hz to 150 Hz
Factory preset:	1 Hz to 35 Hz
Filter options:	0.05 or 1 Hz HP, 35 or 150 Hz LP
Alternative signal:	Heart Rate Mode
Notch filter:	50/60 Hz user-controlled switch; typically not required-factory preset OFF. See Appendix for additional hardware-specific output options.
Noise voltage (shorted inputs):	0.9 μV rms (bandwidth of 0.05 Hz to 150 Hz)
Output voltage range:	±10 V (receiver output)
Input voltage range:	up to 10 mV P-P
Operating time:	72-90 hours

Figure 8. Appearance of BN-RSPEC device.

Results and Discussion

Results of Impedance Measurement by Electrodes

We supposed to analyze the fundamental property of electrode through the impedance measurement by electrodes. The impedance measurement was completed by experimental evaluation through the electrode having size of 2×2 cm (Figure 9). As a result, sample No. 5, 6, 7, and 8 electrodes were close to the property of standard electrode and had lower rates of impedance changes. Therefore, these electrodes had a fundamental property of suitable electrode (Table 5,



$$Z_{ab} = Z_{b1} + Z_{e1} + Z_x$$
$$Z_{bc} = Z_{b2} + Z_{e2} + Z_x$$
$$Z_{ac} = Z_{b1} + Z_{b2} + (Z_{e1} + Z_{e2})$$
If we assume, $Z_{b1} = Z_{b2} = Z_b$
$$Z_{ac} = 2Z_b + (Z_{e1} + Z_{e2})$$
If we assume, $Z_{e2} = Z_{e1} = Z_e$
$$Z_{ac} = (Z_b + Z_e)/2$$
thus, $Z_x = Z_{ab} - (Z_{ac}/2)$
or $Z_x = Z_{bc} - (Z_{ac}/2)$

Figure 9. Method of the impedance measurement.

Table 5. Result of the impedance measurement Unit: Re(kΩ)

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
20 Hz	387.78	450.62	353.95	214.26	172.77	172.93	152.26	221.60
30 Hz	360.45	402.39	320.25	211.51	140.21	135.94	104.01	176.62
50 Hz	304.86	356.51	279.52	200.17	113.29	101.39	64.99	134.25
80 Hz	249.91	320.15	240.43	198.36	97.75	81.90	42.15	107.92
120 Hz	199.81	286.32	212.70	214.08	88.66	70.65	32.01	91.64
180 Hz	163.30	250.49	180.19	195.52	81.13	62.21	24.25	78.94
250 Hz	133.94	223.45	156.01	180.83	76.36	57.36	19.51	70.65
350 Hz	108.55	198.79	132.14	164.64	71.93	53.24	15.76	62.95
500 Hz	84.11	171.23	107.74	146.59	67.13	50.17	12.73	55.39
1000 Hz	50.82	123.12	67.25	109.89	56.35	44.40	8.80	42.26

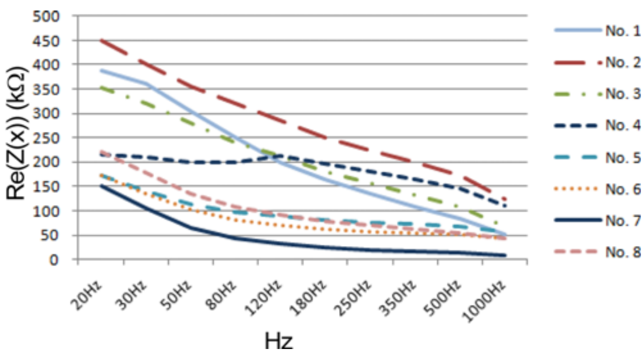


Figure 10. Graph of the impedance measurement.

Figure 10). Sample No. 5, 6, 7, and 8 having two strands of 50 μm silver thread was analyzed to be stable the knitted fabric with higher conductivity than sample No. 1, 2, 3, and 4 having one strand.

Electrocardiogram Signal Evaluation of Textile Electrode

Evaluation according to Electro-Thread Design

16 types of electrode used for this experiment were consisted of 8 electrodes (Large) with 5×2 cm (width× length) and 8 electrodes (Small) with 2×2 cm (width×length). To evaluate the property for the optimal electrode efficiency, the results analyzed poly 30d covering, TM number, and ECG signal by electro-thread (silver thread) number are as following.

As the result of analyzing the size of ECG signal according to poly 30d covering, Electrode No. 1 Small (0.96 V), No. 1 Large (0.99 V), No. 3 Small (1.01 V), No. 3 Large (1.12 V), No. 5 Small (1.33 V), No. 5 Large (1.70 V), No. 7 Small (2.85 V), and No. 7 Large (3.01 V) having no covering were indicated to have larger signal amplitude than Electrode No. 2 Small (0.64 V), No. 2 Large (0.85 V), No. 4 Small (0.72 V), No. 4 Large (0.84 V), No. 6 Small (0.98 V), No. 6 Large (1.40 V), No. 8 Small (1.44 V), and No. 8 Large (2.30 V) having covering. This was analyzed as which Electrode No. 1, No. 3, No. 5, and No. 7 without poly 30d covering have large signal amplitude because conductive silver thread is configured to touch the skin directly, on the other hand Electrode No. 2, No. 4, No. 6, and No. 8 with poly 30d covering had relatively small signal amplitude due to the small region on the skin touched by it.

As the result of analyzing the signal amplitude according to TM of conductive electro-thread (silver thread), the measurement signal amplitude of Electrode No. 1 Small (0.96 V), No. 1 Large (0.99 V), No. 5 Small (1.33 V), and No. 5 Large (1.70 V) having 700 TM were smaller than Electrode No. 3 Small (1.01 V), No. 3 Large (1.12 V), No. 7 Small (2.85 V), and No. 7 Large (3.01 V) having 1300 TM (Table 6). That is, compared to 700 TM of conductive silver thread, the electrode with 1300 TM is estimated to have a larger signal amplitude. This is because the structure of 1300

Table 6. Comparison of mean signal amplitude and mean SNR of all subjects by electrode types

Electrode		Signal (V)	Noise (V)	SNR (dB)
No. 1	Large	0.99	0.021	33.47
	Small	0.96	0.010	39.66
No. 2	Large	0.85	0.022	31.79
	Small	0.64	0.010	36.06
No. 3	Large	1.12	0.028	32.04
	Small	1.01	0.012	39.74
No. 4	Large	0.84	0.030	29.76
	Small	0.72	0.011	37.71
No. 5	Large	1.70	0.031	34.78
	Small	1.33	0.011	41.65
No. 6	Large	1.40	0.031	33.58
	Small	0.98	0.010	39.82
No. 8	Large	2.32	0.030	37.77
	Small	2.12	0.007	49.62
No. 9	Large	2.01	0.030	36.52
	Small	1.86	0.011	44.52

TM of conductive silver has much higher amount of exposure of silver thread, compared to 700 TM. Therefore, it increases the area of contact with the skin, and the signal amplitude has become larger.

In addition, the result of signal amplitude and SNR by the number of electro-thread (silver thread) indicated that the signals and SNR of Electrode No. 5 Small (1.33 V, 41.65 dB), Electrode No. 5 Large (1.70 V, 34.78 dB), Electrode No. 7 Small (2.85 V, 49.62 dB), and Electrode No. 7 Large (3.01 V, 49.62 dB) with two strands of electro-thread(silver thread) were larger than the signals and SNR of Electrode No. 1 Small (0.96 V, 39.66 dB), Electrode No. 1 Large (0.99 V, 33.47 dB), Electrode No. 3 Small (1.50 V, 39.47 dB), and Electrode No. 3 Large (1.12 V, 32.04 dB) with one strand of silver thread. This includes Electrode No. 5 and No. 7 with two strands of silver thread and is due by increasing the skin touch region of electro-thread (Table 6). The signal amplitude and SNR of Electrode No. 6 Small (0.98 V, 39.82 dB), Electrode No. 6 Large (1.40 V, 33.58 dB), Electrode No. 8 Small (1.44 V, 44.52 dB), and Electrode No. 8 Large (2.30 V, 36.52 dB) with poly 30d covering and two strands of silver thread were larger than the signal amplitude and SNR of Electrode No. 2 Small (0.64 V, 36.06 dB), Electrode No. 2 Large (0.85 V, 31.79 dB), Electrode No. 4 Small (0.72 V, 37.71 dB), and Electrode No. 4 Large (0.84 V, 29.76 dB) with poly 30d covering and one strand of silver thread.

Summarizing the previous results, with the increasing number of silver thread and TM numbers, and without the poly 30d covering, it increases the amount of exposure of the covering to the external. This can increase the area of contact with the skin for the silver thread, which is the

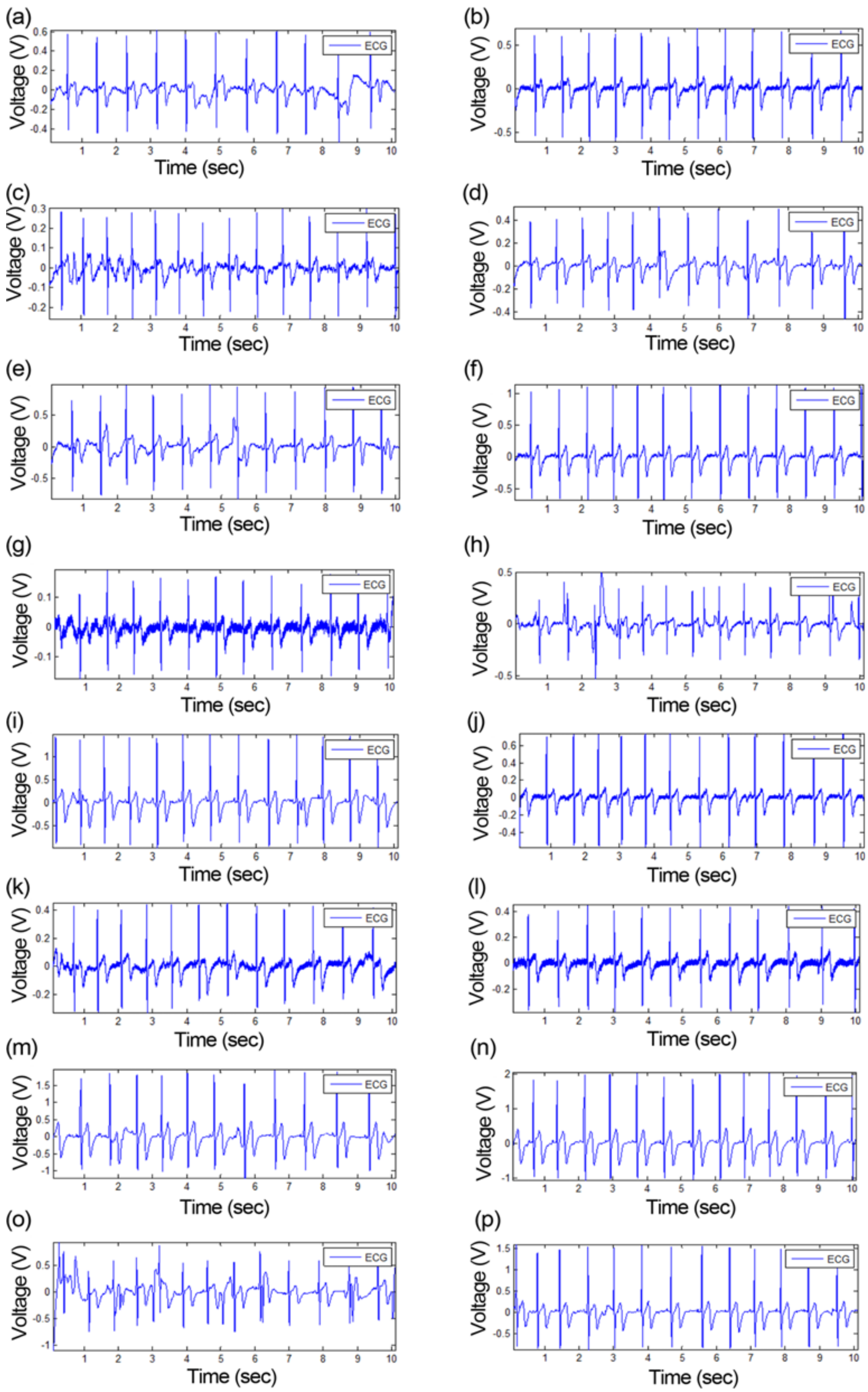


Figure 11. Example of signal according to electrode size (Subject 4); (a) electrode no. 1 large, (b) electrode no. 1 small, (c) electrode no. 2 large, (d) electrode no. 2 small, (e) electrode no. 3 large, (f) electrode no. 3 small, (g) electrode no. 4 large, (h) electrode no. 4 small, (i) electrode no. 5 large, (j) electrode no. 5 small, (k) electrode no. 6 large, (l) electrode no. 6 small, (m) electrode no. 7 large, (n) electrode no. 7 small, (o) electrode no. 8 large, and (p) electrode no. 8 small.

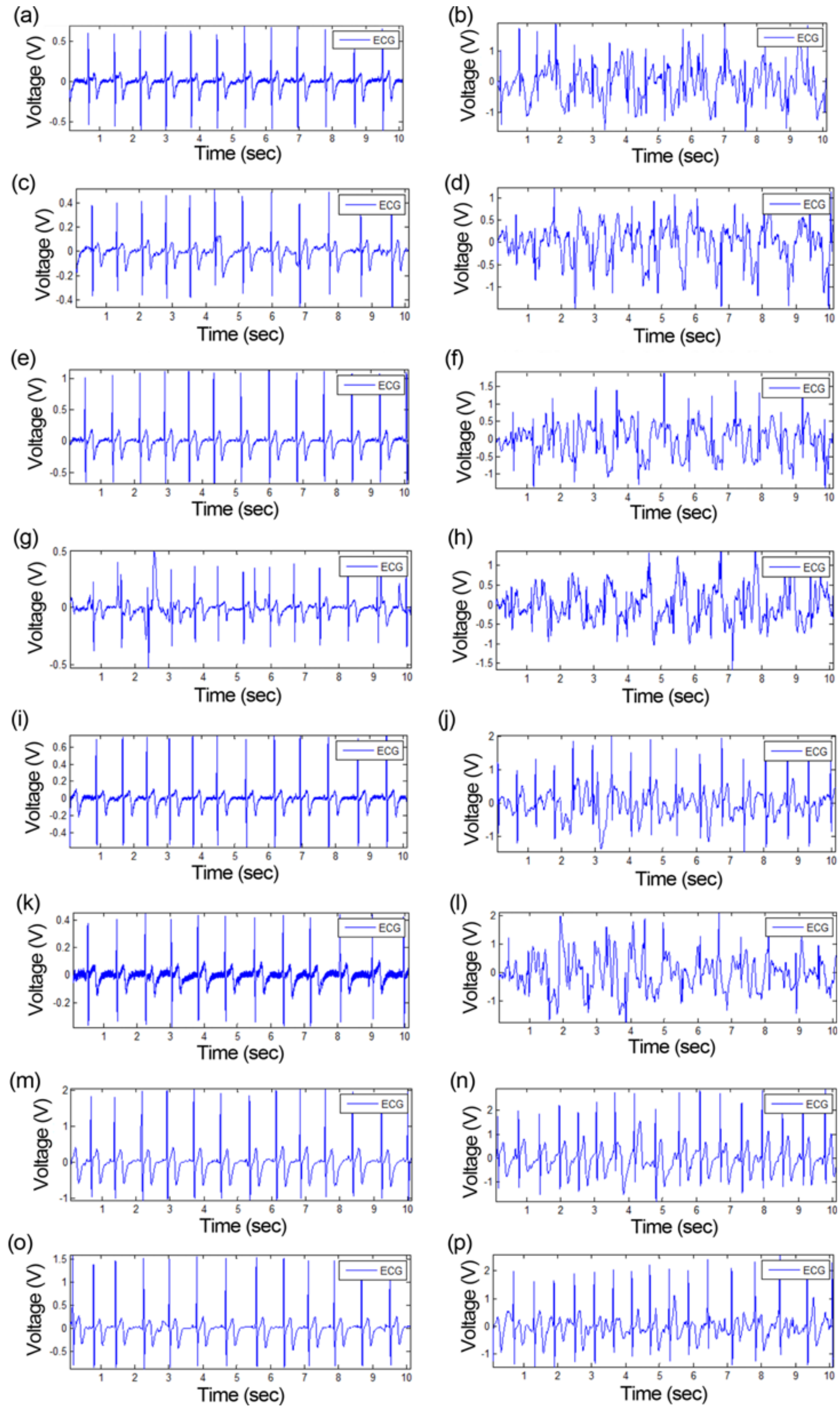


Figure 12. Signal comparison according to electrode in standing and walking (Subject 4); (a) electrode no. 1 standing, (b) electrode no. 1 walking, (c) electrode no. 2 standing, (d) electrode no. 2 walking, (e) electrode no. 3 standing, (f) electrode no. 3 walking, (g) electrode no. 4 standing, (h) electrode no. 4 walking, (i) electrode no. 5 standing, (j) electrode no. 5 walking, (k) electrode no. 6 standing, (l) electrode no. 6 walking, (m) electrode no. 7 standing, (n) electrode no. 7 walking, (o) electrode no. 8 standing, and (p) electrode no. 8 walking.

covering, and the measurement signal increases as well.

Evaluation by Electrode Size

The size of electrodes were composed with total 16 electrodes in 8 Electrode (Large) of 5×2 cm and in 8 Electrode (Small) of 2×2 cm, and the suitable electrode size was derived by comparing measured Electrocardiogram signals.

As the result of comparing signal amplitude according to the electrode size, the signal amplitude in large electrodes, which are Electrode No. 1 Large (0.99 V), No. 2 Large (0.85 V), No. 3 Large (1.12 V), No. 4 Large (0.84 V), No. 5 Large (1.70 V), No. 6 Large (1.40 V), No. 7 Large (2.32 V), and No. 8 Large (2.01 V), were measured larger than in small electrodes of Electrode No. 1 Small (0.96 V), No. 2 Small (0.64 V), No. 3 Small (1.01 V), No. 4 Small (0.72 V), No. 5 Small (1.33 V), No. 6 Small (0.98 V), No. 7 Small (2.12 V), and No. 8 Small (1.86 V). This could be easy for signal extractions because the larger electrode size have a large area contacted to the body.

However, as the result of comparing noise signals by electrode sizes, the noises of Electrode No. 1 Large (0.021 V), No. 2 Large (0.022 V), No. 3 Large (0.028 V), No. 4 Large (0.030 V), No. 5 Large (0.031 V), No. 6 Large (0.031 V), No. 7 Large (0.030 V), and No. 8 Large (0.030 V) were higher than Electrode No. 1 Small (0.010 V), No. 2 Small (0.010 V), No. 3 Small (0.012 V), No. 4 Small (0.011 V), No. 5 Small (0.011 V), No. 6 Small (0.010 V), No. 7 Small (0.007 V), and No. 8 Small (0.011 V). This could be due by the results that the large electrode made to increase the noise by more contacted to the skin (Table 6). In other words, the larger electrode has larger areas based on the body surface, compared to the smaller electrode, so it has larger signal at measurement. However, with the body movements, the larger electrode creates more noises due to friction at the contacted areas, and the contact with the body surface becomes larger, which increases the size of the noise.

When generalizing above two results, therefore, Electrode No. 1 Small (39.66 dB), No. 2 Small (36.06 dB), No. 3 Small (39.74 dB), No. 4 Small (37.71 dB), No. 5 Small (41.65 dB), No. 6 Small (39.82 dB), No. 7 Small (49.62 dB), and No. 8 Small (44.52 dB) showed higher SNR values than Electrode No. 1 Large (33.47 dB), No. 2 Large (31.79 dB), No. 3 Large (32.04 dB), No. 4 Large (29.76 dB), No. 5 Large (34.78 dB), No. 6 Large (33.58 dB), No. 7 Large (33.77 dB), and No. 8 Large (36.52 dB), so that the small electrode was more suitable for apparel applications and electrocardiogram signal measurement than the large electrode (Table 5).

Evaluation in Standing and Walking

As the result of the experiments by the electrode size, we could confirm that the small electrode had more stable for measurement than the large electrode and supposed to derive suitable electrode from 8 small electrodes by evaluating and analyzing the signal difference from in standing and in walking.

The evaluation result of electrodes in walking showed large signal amplitude with two strands of silver thread than one strand which is similar to the result in standing. Electrode No. 5 (2.22 V), No. 6 (1.73 V), No. 7 (3.51 V), and No. 8 (3.22 V) having two strands of silver thread indicated larger signal amplitude than Electrode No. 1 (1.82 V), No. 2 (1.28 V), No. 3 (1.98 V), and No. 4 (1.09 V) having one strand. And also the measuring signal amplitude in Electrode No. 1 (1.82 V), No. 3 (1.98 V), No. 5 (2.22 V), and No. 7 (3.51 V) without poly 30d covering were relatively larger than in Electrode No. 2 (1.28 V), No. 4 (1.09 V), No. 6 (1.73 V), and No. 8 (3.22 V) with poly 30d covering (Table 7). All electrodes showed the result that the signal amplitude is increasing when walking than standing. It is thought that the sweats created while walking increases the skin moisture, which increases adhesion and conductivity of the electrode.

Rather than in standing, the signal distortion was enlarged by increasing motion artifact due to body movements in walking (Figure 12), and the result compared the values from measurement noises in walking was identical. As the result of analyzing SNR generalized signal and noise, most electrodes showed higher signal amplitude in walking but the SNR in walking was decreased than in standing due to the noise increase by motions. From the compared results for each electrode, Electrode No. 5 (34.27 dB), No. 6 (32.96 dB), No. 7 (38.41 dB), and No. 8 (37.69 dB) having two strands of silver thread showed higher SNR than Electrode No. 1 (32.47 dB), No. 2 (27.39 dB), No. 3 (35.10 dB), and No. 4 (26.09 dB) with one strand of silver thread. The noise had similar to SNR regardless of the specification of electro-

Table 7. Mean signal comparison of subjects in standing and walking

Electrode		Signal (V)	Noise (V)	SNR (dB)
No. 1	Standing	0.96	0.010	39.66
	Walking	1.82	0.043	32.47
No. 2	Standing	0.64	0.010	36.06
	Walking	1.28	0.055	27.39
No. 3	Standing	1.01	0.012	38.50
	Walking	1.98	0.035	35.10
No. 4	Standing	0.72	0.011	36.58
	Walking	1.09	0.054	26.09
No. 5	Standing	1.33	0.011	41.65
	Walking	2.22	0.043	34.27
No. 6	Standing	0.98	0.010	39.82
	Walking	1.73	0.039	32.96
No. 7	Standing	2.12	0.007	49.62
	Walking	3.51	0.042	38.41
No. 8	Standing	1.86	0.011	44.52
	Walking	3.22	0.042	37.69

thread composing electrodes and SNR results were also similar to the results of signal amplitude.

Electrode No. 7 had 49.62 dB in standing and 38.42 dB in walking which are the highest SNR values and the second highest SNR was from Electrode No. 8 (Standing: 44.52 dB, Walking: 37.69 dB), so that it represented the suitability as the electrode (Table 7).

R peaks from Electrode No. 5, No. 7, and No. 8 were clearly confirmed in overall waveform, and the stability of signals was also higher than other electrodes (Figure 12).

As the result of analyzing 8 types of electrode in walking, it could confirm that Electrode No. 7 represents the highest signal. This seems to be an identical result from optimized electrode in Standing.

Conclusion

In this study, 8 types of electro-thread were developed, and total 16 types of textile electrode having two different sizes were developed and evaluated. As the result of analyzing SNR which is an index of signal accuracy, electro-thread with two strands of silver thread had higher SNR than one strand in standing. Additionally, in the case of the thread without poly 30d covering, it could be accurate for electrocardiogram measurement because the silver thread having many TM was designed to expose a lot and so it led to increase the contact to the skin.

This showed the same result in walking and so it was evaluated that textile electrode is suitable to measure an electrocardiogram with the thread having high contacts between silver thread and skin even in movements. The electrode with 2×2 cm had larger signal amplitude than 2×5 cm and presented to increase overall SNR due to small noise. While the large electrode enlarged signal amplitude by high contacts to the skin, the contacted noise by contour line of body was also increased and the overall SNR was decreased. So we could confirm that the large contact area is not the main factor for the electrode.

Based on the previous result, the availability of electrocardiogram measurement was identified in the small electrode and the signals in 8 types of small electrode in walking were measured and analyzed to evaluate signal and noise for movements. The measurement signal amplitude in walking is larger than in standing, so this could be considered as the result that skin sweating in walking increased adhesion and contact on skin and brought more accurate electrocardiogram measurement.

Summarizing the above results, the higher amount of electro-thread and without poly 30d covering could expose to the surface and its measuring signal was enlarged by more skin contacts. Furthermore, because the small electrode increased higher contacts to skin and minimized motion artifact, it was analyzed that the large electrode couldn't induce the accuracy of electrocardiogram signal. Therefore, for designing and realizing electrodes of electrocardiogram measurement, the small electrode could be suitable for electrode configuration to increase the conductivity onto electrode surface and to minimize motion artifact.

Since this study has been progressed only in males, however, the study with applying and evaluating females and various ages should be executed in future. Also, because there is a limitation to derive the optimized electrode size by two types of electrode, the study with various electrode sizes is necessary in future.

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