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Time Relation among Clothing Pressure Developed at Waistband, Respiratory Movement, and Girth of Abdomen – Using by Hydrostatic Pressure-balanced Method –

Tamaki Mitsuno [*1] *and Kazuo Ueda* [*2]

[*1] Faculty of Education, Shinshu University, 6-ro, Nishi-nagano, Nagano-city, Nagano 380-8544, Japan
[*2] Faculty of Science, University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

Abstract: Time relation among clothing pressure developed at waistband, respiratory movement, and girth of abdomen were investigated. The time constants of 3 sensors to monitor these waves in this measuring system were examined, and were 0.016s, 268.9ms, and 57.0ms corresponded to that order. Therefore, this measuring system for the clothing pressure could sufficiently follow the changes of waistband-pressure which might be caused by either respiratory movements or changes in posture, and the most suitable method to measure the clothing pressure. Subjects were 10 women aged from 20 to 22 years old, and 3 waves measured under 3 conditions : non waistband, wearing waistband with a perfect fitting length and a tight fitting length in free respiration. These waves analyzed by Fourier transform to examine these constitutional frequencies which were 3.85±0.99s, 3.85±0.92s, 3.72±0.85s and nearly equal. By the way, the time lags of peak in girth of abdomen and in respiratory movement were calculated from their cross spectra, the time became significantly late. So, the timing of air flowed into the body became significantly late, because of worn waistband. We distinguish whether the body region influenced by respiratory movement, and have to investigate a permissible limit of the pressure including a change of a respiratory function in the future.

(Received 24 June, 2009 ; Accepted 8 September, 2009)

1. Introduction

Recently, the direct methods came to be employed widely to measure the clothing pressure as an index of wearing-comfort for an advantage of reasons as follows. Because the sensor was lightweight and small size, clothing pressure came to be measured without deforming of wear appearance. A wear feeling of the sensor dose not have a discomfort, the relation between pressure feeling and clothing pressure were able to examine. The direct methods for measuring the clothing pressure were divided into two methods. One method was for recording a cutaneous pressure by using a needle hypodermally inserted which was connected to a low pressure transducer [1]. The other one was for recording it by using non-elastic small bag as a sensor placed between skin surface and clothes. In the former method, the wearing appearance was not deformed as there was no extraneous substance between the clothes and the human body surface. However, this was not suitable to measure the wearing-comfort as the subjects complained about the pain on insertion of the needle sensor. In the latter method at present, air [2-5, they reported following measuring system, AMI] or water [6-12] was used as pressure-conductive media to the sensor bag with the transducer. We employed the water bag method which was called hydrostatic pressure-balanced method, and would report the reason later. By the way, the changes of clothing pressure developed between the waistband and the body surface when the waistband was attached to the abdomen (It is called waistband-pressure hereafter.) was observed with the changes in respiratory movement and girth of abdomen, but these detailed relations have been not reported. Therefore we examined the time relation among these 3 changes, and we report some knowledge to affect to the human body.

2. Experimental method

The clothing pressure, the respiratory movement, and the girth of abdomen were measured by a hydrostatic pressure-balanced method which is the measuring system for clothing pressure. The specifications of this measuring system were shown in Table 1 [8]. Refer to the previous papers about the measuring method [6/7] more details. Three output wave patterns of this measuring system from each amplifier were taken in PC by as A/D conversion board [AD12-16TA (98)H, KISSEI COMTEC CO.,

Table 1 Specification of hydrostatic pressure-balanced method (water bag method)

Item	Quality
Pouch: size and volume*	Flat bag, 25×15×0.2mm in which 0.08-0.21 ml of water is enclosed
material*	Hard polyethylene membrane having a thickness of 18 μm
Calibration*	Y = aX, a = 0.99 (-3.3 to 20.0 kPa: -25 to 151 mmHg) Y: Reading of the system X: Applied loads
Maximum drift of zero point*	99.9Pa/h (0.75 mmHg/h) at constant temperature, 35, 37, 40℃
Temperature drift*	No detectable change
Time constant	Clothing pressure: 0.016 s*,** Girth of abdomen: 0.057s**** Respiratory movement: 0.269s****
Measurable radius curvature***	2.5 mm
Resolution***	5.3Pa (0.05 mmHg)
User's feeling*	Unconscious

* : These items were already reported by Mitsuno et al. [6], ** : This item was already reported by Mitsuno and Ueda [7], *** : These items were already reported by Mitsuno [8], **** : These items will be reporting in this paper.

TOKYO] at sampling frequency of 200 Hz and analyzed by Fourier transform (FFT) and cross spectra of two waves (using by BIMUTAS, KISSEI COMTEC CO., TOKYO). The experiment was done in an artificial climate room (environmental temperature : 24.5 ± 0.3℃, relative humidity : 50.0 ± 0.5 %, air current : 0.08 ± 0.06 m/s, intensity of illumination : 770.1 ± 61.0 lx, by using facilities of Shinshu University).

2.1 Time constants of response in this measuring system

The line drawing of the measuring apparatus is shown in Fig. 1, in order to measure the time constants of responses.

2.1.1 Clothing pressure sensor (a pouch)

The Pouch E was fixed on the Laboratory jack C, which might adjust the height of the Pouch keeping with a horizontal position. A dotted line of Photo-projector A and Photo-receiver A’ of an optical sensor (PLX-105W, Hokuyo Automatics Co. Osaka) was arranged in parallel with a plane just above the Pouch. The Weight B, a load to the Pouch, was pulled up easily through the Pulley D. The bottom end of the Weight B on the Pouch was adjusted its level so as to just intercept the light of the optical sensor by moving the Laboratory jack up and down. When the Weight B was pulled up quickly, at the same time, a beam of light from the Photo-projector A entered into the Photo-receiver A’, and optical sensor of receiver operated. In this way, we could monitor the time when the Weight B was pulled upward. Furthermore, the light monitor for the Weight unloading and output of

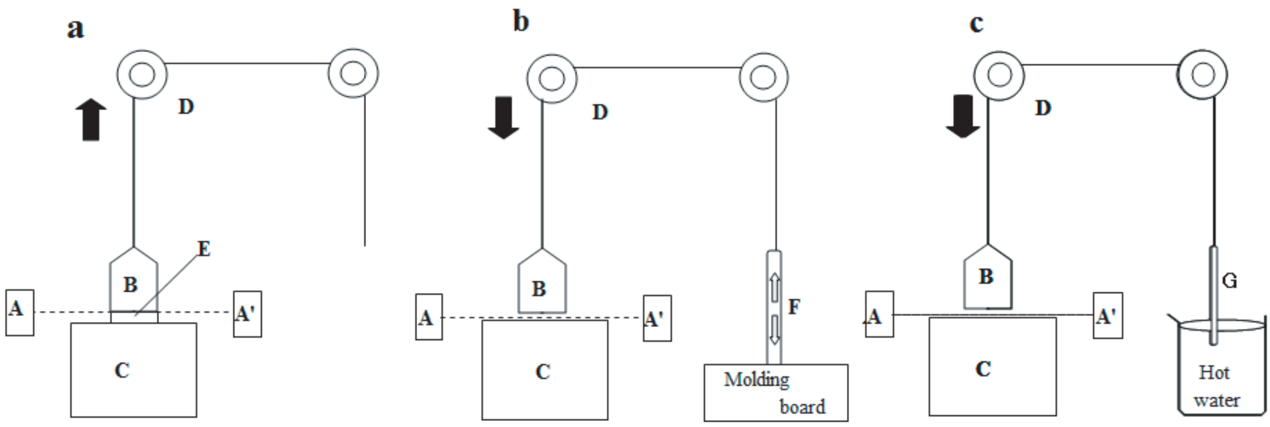

Fig. 1 Measuring apparatus for time constant of responses
a : Clothing pressure, b : Girth of abdomen, c : Respiratory movement. A : Photo-projector, A’ : photo-receiver, B : Load, C : Laboratory jack, D : Pulley, E : Detector pouch, F : Sensor for thoracic pickup fixed to the molding board, G : Thermistor as monitor for respiratory movement soaked in the hot water about 40 ℃.

Table 2 Physical characteristics of subjects and waistband-pressure

Subject (Unit)	Age (Year)	Hight (m)	Weight (kg)	Waist girth(cm)	"Perfect-fitting" Length (cm)	"Perfect-fitting" Constrictive ratio (%)	Waistband-pressure(hPa)	"Tight-fitting" Length (cm)	"Tight-fitting" Constrictive ratio (%)	Waistband-pressure(hPa)	BMI (kg/m^2)
A	22	1.55	42.6	59.4	61.2	-3.0	3.9 ± 3.3	58.9	0.8	14.3 ± 5.6	17.7
B	22	1.57	46.6	61.5	65.8	-7.0	5.0 ± 1.1	59.9	2.6	11.5 ± 8.6	18.9
C	22	1.61	48.9	64.0	65.9	-3.0	5.2 ± 2.7	63.9	0.2	10.1 ± 4.3	18.9
D	21	1.62	50.8	65.2	69.1	-6.0	3.7 ± 2.4	65.9	-1.1	10.1 ± 3.1	19.4
E	22	1.56	47.6	60.1	62.8	-4.5	10.9 ± 10.6	56.4	6.6	27.1 ± 22.8	19.6
F	22	1.56	49.2	64.1	65.8	-2.7	3.9 ± 2.0	63.7	0.6	12.9 ± 4.1	20.2
G	22	1.54	48.8	63.9	65.0	-1.7	4.9 ± 2.1	63.4	0.8	10.9 ± 4.5	20.6
H	22	1.56	50.6	64.3	64.9	-0.9	8.6 ± 3.0	63.4	1.4	10.6 ± 3.3	20.8
I	22	1.59	54.9	67.1	69.6	-3.7	4.0 ± 1.7	66.4	1.0	11.4 ± 3.8	21.7
J	21	1.63	58.3	73.3	76.9	-4.9	4.5 ± 0.8	74.3	-1.4	12.3 ± 3.0	21.9
Average	21.8	1.58	49.8	64.3	66.7	-3.7	5.5	63.6	1.2	13.1	20.0
SD	0.4	0.03	4.3	3.9	4.4	1.9	3.0	4.9	2.2	6.3	1.3

Length shows the lengths of waist bands which were chosen by subjects' pressure feeling of "Perfect- fitting" or "Tight-fitting". Constrictive ratio shows the percentage of waistband length for waist girth.

pressure measuring system were simultaneously recorded. Upon unloading, time required until the output pressure signal being attained to 1/e of the final value (0) was calculated (time constant).

2.1.2 Sensor (thoracic pickup) for girth of abdomen

Fig. 1b shows the apparatus of obtain the time constant of the response to the girth of abdomen. Electric potential changes corresponding to length (girth of abdomen) were measured through the thoracic pickup Sensor F, one end of which was fixed firmly to the molding board. The position of the molding board was adjusted so as to make the bottom of Weight B several millimeters short from the sensor light. When the Weight B, by which the Sensor F has been stretched a little in advance, was quickly pulled down, the Sensor F was further stretched and the change of electric potential was recorded. At the same time, the sensor light was intercepted by the abrupt descent of the Weight B. In this way the moment of the stretching was monitored. Upon the quick stretching, the time constant was calculated from the electric potential change by using the same method described previously.

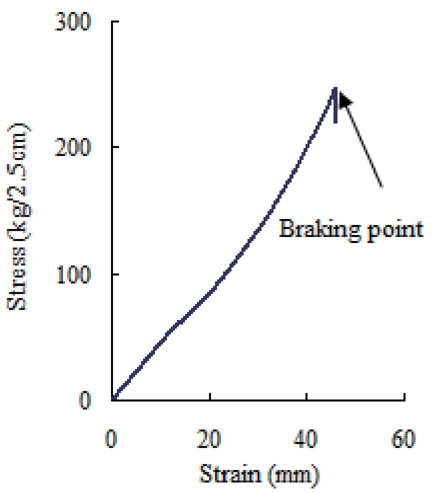

Fig. 2 A typical example of experimental belt

2.1.3 Sensor (thermistor) for respiratory movement

Fig. 1c shows the apparatus for the time constant of the respiratory movement. Thermistor G as a monitor for the respiration was soaked beforehand in hot water about 40℃, which was pulled up from hot water into the air. The moment of the quick pull was monitored since the light of Photo-projection A was intercepted by the Weight B descended (arrow direction). The time constant was calculated from the same method described above.

2.2 Clothing pressure developed at waistband

Subjects were 10 women aged from 20 to 22 years old, and their physical characteristic was shown in Table 2. Their BMI indices ranged from 17.7 to 21.9, which showed various figures from slender to normal. The waistband used in this paper was the inside belt in 2.5cm width of plain weave fabric, which the warp were polyester spun yarn and the weft were nylon filament yarn. Thickness of the belt was 0.660 ± 0.006 mm which was measured by using THICKNESS GAUGE (TOKYO SEIMITSU KOGYO CO., n = 10). The density of material was measured as 14 threads / cm in warp and weft direction, we examined tensile strength of the waistband in warp direction. A typical example of stress

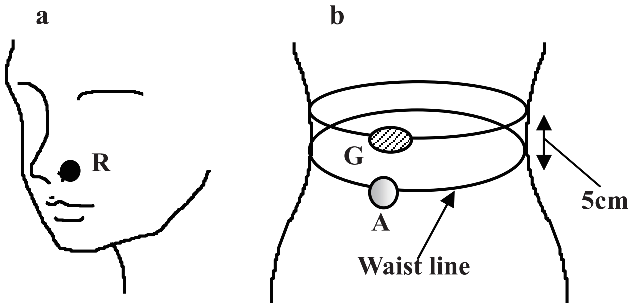

Fig. 3 Measuring regions

a : For respiration, b : For both girth of abdomen and waistband-pressure. R : Thermistor fixed around nostril measure the respiration, G : Thoracic pickup wound around abdomen to measure the girth of abdomen at 5 cm cranially from waist line, A : Pouch put on a line 3 cm from the anterior median line in right half of the body to measure the waistband-pressures.

strain curve using by tension tester (UTM-Ⅲ-100, TOYO) with JIS 1096-1990 method was shown in Fig. 2. The stress caused to a waistband was almost in the immediate vicinity of the origin, and strain was limited to around 0.2 % according to many estimates (See previous paper [6-8]). The waistband-pressure was measuring by using this measuring system. The time relation among the waistband-pressure, the girth of abdomen, respiratory movement was examined. Measuring regions are shown in Fig. 3. The Thermistor as the monitor for the respiratory movement was fixed a tape at region R ; the Thoracic pickup for the change in the girth of abdomen was wound at region G ; the Pouch for the waistband-pressure was placed between the waistband and the skin surface at region A. The respiratory movement and the girth of abdomen were measured with waistband-pressure in 3 following conditions : the subjects not fastened waistband, they themselves fastened the waistband around their waist until a perfect-fitting or a tight-fitting sensations. The perfect-fitting length has a long 3.7 ± 1.9 % (mean ± SD) than their nude length (See Table 2 for reference. Constrictive ratio : -7.0 to -0.9 %), and the tight-fitting length which they judged to be “tight” was 98.8 ± 2.2 % (Constrictive ratio : -1.4 to 6.6 %). In other words, in the case of the subject who preferred a long length belt to nude length, the belt was put on caudally 1 cm from waist line.

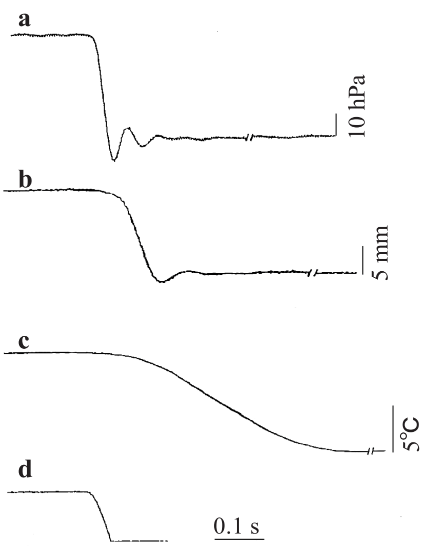

Fig. 4 Typical examples of time constants of sensor responses in measuring system
a : Pouch for clothing pressure. b : Thoracic pickup for girth of abdomen. c : Thermistor for respiratory movement. d : Photo-sensor for monitor

3. Results

3.1 Time constants of response in this measuring system

Fig. 4 shows the records of decreasing output of the apparatus for the clothing pressure (a), for the girth of abdomen (b), for the respiratory movement (c), and for the optical sensor (d) to measure the time constants of the response (See Fig. 2 for reference.). From Fig. 4a, the time constant of the pouch was calculated to be 16.0 ± 2.0 ms (mean ± SD, n = 59). From Fig. 4b and c, the time constants of the thoracic pickup and thermistor were 57.0 ± 16.5 ms (n = 67) and 268.9 ± 51.4 ms (n = 65) respectively. Meanwhile, as for the present subjects, respiratory periods was 3.85 ± 0.92 s (n = 10). Posture changes originate from muscular contractions. Although there is a little difference in a duration of muscular contraction by kinds of muscles, for example, the duration

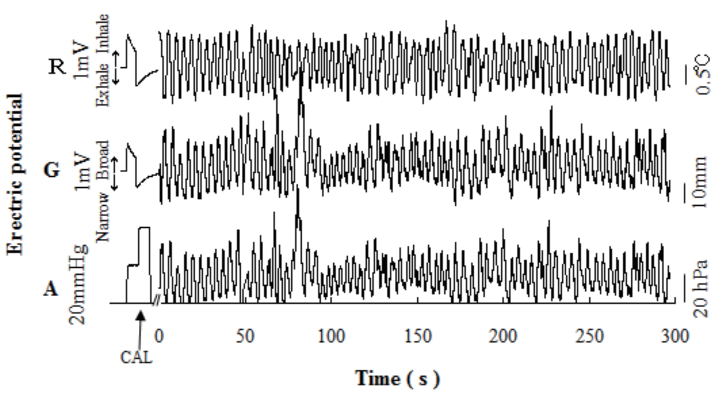

Fig. 5 Typical simultaneuos records of respiration (Trace R), girth of abdomen (Trace G), and waistband-pressures (Trace A). See Fig. 3 for legends. Subject E

of human limb muscle was described as 100 ms (0.1 s) [13]. Therefore, this measuring system for the clothing pressure could sufficiently follow the changes of waistband-pressure which might be caused by either respiratory movements or changes in posture.

3.2 Waistband-pressure, respiratory movement and girth of abdomen

A typical example of three source waves of the respiratory movement, the girth of abdomen, and waist-band-pressure with tight-fitting length, which obtained in one and the same subject during erect standing for 5 minutes, is shown in Fig. 5. A free respiration was able to clearly distinguish between exhalation and inhalation phases and average of waistband-pressure was shown in Table 2. According to a visual observation, the 3 waves seemed to be increased or decreased at nearly the same time. When the respiratory wave (R) was disordered for a moment, it brought changes of periodicity in both the girth of abdomen (G) and the waistband-pressure (A). The results of Fig. 5, analyzed by FFT to examine these constitutional frequencies, are shown in Fig. 6 and cross spectra of two waves arbitrarily chosen from the 3 waves are shown in Fig. 7. All power spectra had practically no power in frequency range more than 1 Hz, so they were traced under 1 Hz. Power spectra of the 6 waves had the same main peak of 0.23 Hz, and a peak profile of the power spectra looked like the same among the 6 waves. The power spectra taken from the other 9 subjects were substantially the same, and the averaged peak frequency of 10 subjects was 0.28 ± 0.06 Hz. And the result was not a difference in perfect-fitting length, and it was 0.28 ± 0.08 Hz. In other words, it was found that the respiratory movement, girth of abdomen, and the waistband-pressure altered in the same periods of subject's own period.

Additionally, a phase (time) lag calculated from the combination of cross spectra is shown Fig. 8-a as the averages of 10 subjects. R-G, R-A, G-A to know the time sequence of R, G, and A (R : respiratory movement, G : girth of abdomen, A : waistband-pressure). The bar graph in R-G (phase lag between the respiratory movement R and the girth of abdomen G) shows that the change of the respiratory movement starts significantly faster than that of the girth of abdomen by 29.7 ± 50.9° (non waistband) 59.1 ± 40.9° (perfect-fitting length) and 60.0 ± 24.4° (tight-

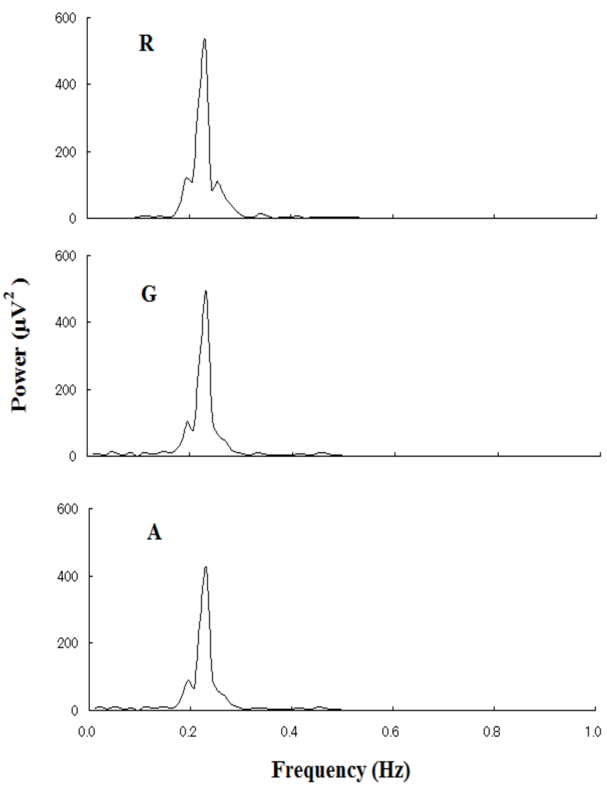

Fig. 6 Power spectra of the 3 waves (respiration, girth of abdomen, and waistband-pressures shown in Fig. 5). Legends of R, G, and A correspond to those of Fig. 5. Subject E

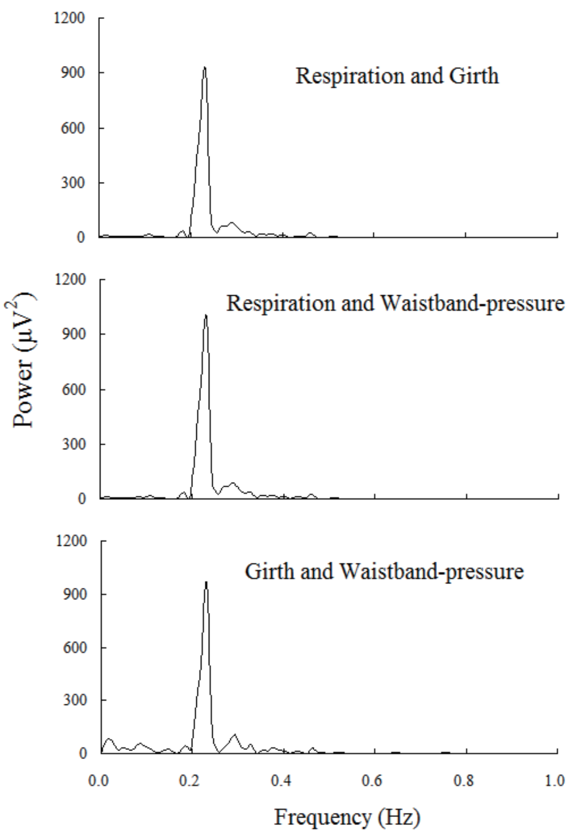

Fig. 7 Cross spectra of two waves arbitrarily chosen from the 3 waves shown in Fig. 6 (respiration, girth of abdomen, waistband-pressures)

Top line : cross spectrum between respiration and girth of abdomen, 2nd line : between respiration and waistband- pressure, 3rd line : between girth and waistband-pressure. Subject E

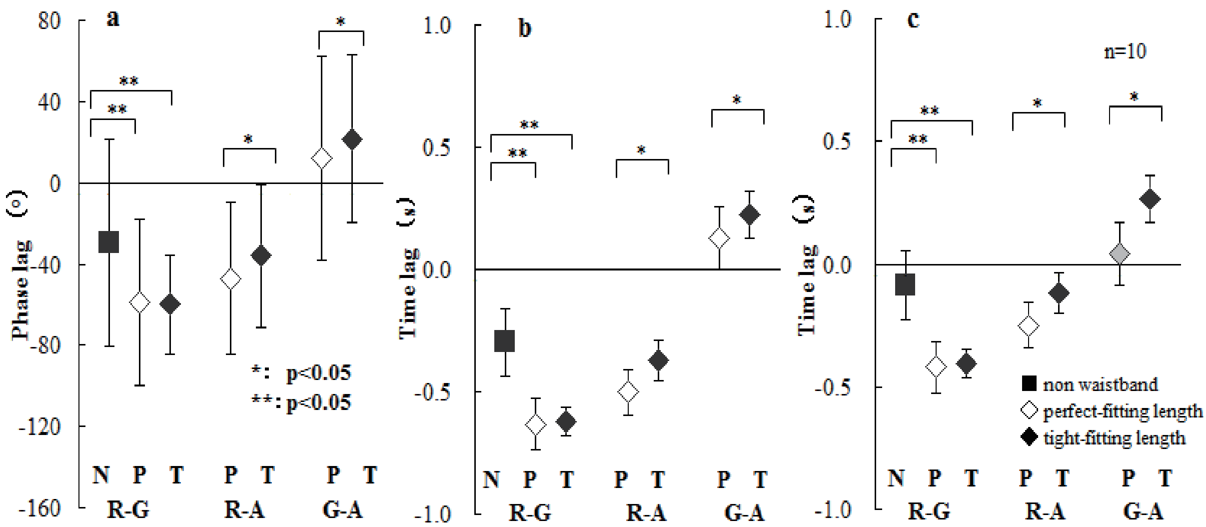

Fig. 8 Phase (time) lag calculated from the combination of cross spectra

a : the results using cross spectra analysis, b : as the results of recalculation considered time lag from phase lag in each waves, c : furthermore, as the results of recalculation considered a true time constant of each sensor. R-G, R-A, G-A show the time sequence of R, G, and A (R : respiratory movement, G : girth of abdomen, A : waistband-pressure). Waistband fitting was shown in 3 conditions as N (non waistband), P (worn perfect-fitting length), and T (worn tight-fitting length). These results were examined by paired t-test.

fitting length). Similarly, the bar graphs R-A and G-A show that the respiratory movement changes significantly faster than waistband-pressure by 47.0±37.2° (perfect-fitting length) and 36.0±34.9° (tight-fitting length), while the girth of abdomen changes significantly faster than the waistband-pressure by 12.0±50.3° (perfect-fitting length) and 21.7±41.4° (tight-fitting length).

4. Discussion

We reported that air or water was used as pressure-conductive media to the sensor bag with the transducer at present, as mentioned above. According to Kominami (the maker for AMI, [14]), the measuring system with an air bag (for example, AMI 3037-2) had a measuring error of ±0.10 kPa (±1.33 mmHg) in the final output. And in this air bag method, a clear change of clothing pressure with respiratory movement has not reported until now. On the other hand, in this measuring system for the clothing pressure, we should make both the sensor bag and the pressure transducer the same height above the ground, because the pressure medium is the water of a specific gravity of 1.0. However, as shown in Table 1, the sensitivity of output was 0.005 kPa, the time constant was as fast as 0.016 s, and clothing pressure changes with respiratory movement could recorded clearly. That is, it is considered that this water bag method is suitable for the study on details of the clothing pressure.

By the way, the relation of phase lags (degree) among the respiratory movement, the girth of abdomen, and the clothing pressure (Fig.8-a) were calculated to time lag, using the average of a respiratory period of 10 subjects wearing no waistband : 3.85±0.99s,a perfect fitting length waistband : 3.85±0.92s, and a tight fitting-length waistband : 3.72±0.85s (Fig. 8-b). Furthermore, the original biological phenomena occurred earlier than the records only with the amount of each time constant of the sensors (described 3-1). As shown in Table 1, the time constant of thermistor monitored respiratory movement was 268.9ms, the thorax pick up sensor monitored the change of girth of the abdomen was 0.057s, and the pouch (a sensor) of clothing pressure was 0.016s. Fig. 8-c was shown the results considered these time constants. In this way, R-G and R-A were negative numbers, so G and A occurred earlier than R, and as the same as G-A was positive number, G occurred earlier than A. That is, the change of girth of the abdomen (G) occurred at first, and next waistband pressure (A) occurred, and the respiratory movement (R) occurred in the last. In addition, the phase lag of R-G in Fig. 8-a ; respiratory movement became significantly late compared with the change of girth of the abdomen when we wore the waistband, in other word, the timing of air flowed into the body became significantly late because of worn waistband. In Fig. 8-c, the time lag between the change of girth of the abdomen and waistband-pressure was not clear worn the perfect-fitting waistband. In the range of the pressure in this experiment, the period of respiratory movement was not changed, but the timing of air flowed into the body became significant late.

According to Majima [15], pneumatic inhalation depends on both an ascent of thorax and a subsidence of the diaphragm. When we try to inhale the air, a group of abdominal muscles contracts so as to move the thorax upwards and as a result the diaphragm is pulled down. So, the girth of the abdomen increases at first. However, the ascent of the thorax is obstructed a little by the waistband, so the girth of region A on the waistline can not increase so easily. When the muscles under the inextensible the waistband increase their activities, so the gap between the waistband and the body surface decreases, and the waistband-pressure changes. By further activation of the abdominal muscles, the air flows passively into the stomach cavity from a nostril. In this way, the rhythm of respiratory movement was changed by waistband although the air flowing into the body. How may abnormality of respiratory rhythm influence the human body?

A heart rate is regulated by a cardiac sympathetic nerve, a parasympathetic, and a baroreceptor which is affected by many factors [16]. Respiratory movement is nominated for one of the factors, and heart rate increase in inhalation phase, and decrease in exhalation one. According to Umemoto et al. [17], who examined mutual coupling relationship between cardiac and respiratory rhythms, and reported abnormality of respiratory rhythm caused abnormality of cardiac rhythm. In previous papers [18/19], we have already investigated skin temperature and salivary secretion were decreased by abdominal pressure with waistband of only 4.4hPa (3.3mmHg) significantly. Pressure stimulus to the abdomen was changed the respiratory rhythm, and was considered to affect the heartbeat rhythm. Moreover, that would lead to the deterioration of many functions of an autonomic nervous system. Morooka [20] reported the working efficiency rather rises when a human abdomen was tightened 1 kPa degree. On the other hand, Sugiura [21] reported we should not press the abdomen strongly, because of respiratory metabolism increased at the time of exercise significantly. These studies related to the same body part of abdomen, but we should not give a conclusion about the effect of the pressure to the abdomen on the work efficiency, because a method and the degree to press the abdomen were different. In the future, we distinguish whether the body region influenced by respiratory movement (Amono et al. [2] reported an example.), and have to investigate a permissible limit of the pressure including a change of a respiratory function. In this paper, we do not measure accurate quantity of exhalation and inhalation. Furthermore, it will be necessary to examine the quantity of exhalation and inhalation, including an oxygen intake and a carbon dioxide discharge.

5. Conclusion

Time relation among clothing pressure developed at waistband, respiratory movement, and the change of girth at abdomen were investigated. The time constants of 3 sensors to monitor these waves in this measuring system were examined, the results were 0.016s, 268.9ms, and 57.0ms in that order. Therefore, this measuring system for the clothing pressure could sufficiently follow the changes of waistband-pressure which might be caused by either respiratory movements or changes in posture. Subjects were 10 women aged 20 years old, and 3 waves measured in 3 conditions : non waistband, wearing waistband with a perfect fitting length and a tight fitting length in free respiration. These waves analyzed by FFT to examine these constitutional frequencies which were 3.85±0.99s, 3.85±0.92s, 3.72±0.85s in that order and nearly equal. By the way, the time lags of peak in girth of abdomen and in respiratory movement were calculated from their cross spectra, the time became significantly late. So, the timing of air flowed into the body became significantly late, because of worn waistband. In the future, we distinguish whether the body region influenced by respiratory movement, and have to investigate a permissible limit of the pressure including a change of a respiratory function.

Acknowledgements

A part of this work was supported by Grant-in-Aid for Scientific Research (C) by Japan Society for the Promotion of Science.

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