Journal of Biomechanical Science and Engineering

Vol. 6, No. 3, 2011

Classification of Health Grade Using Bio-Check Unit and Health Index*

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Abstract

A bio-check unit and health index were developed to evaluate personal health grade. The bio-check unit conducts health-related surveys and noninvasive measurements of physiological signals. Four health indices were defined such as cardiovascular index, stress index, obesity index, and management index. Programs were developed to evaluate scores of the four health indices from measured physiological signals and answers of survey questions. In order to obtain distributions of the health index scores with age, a clinical study was performed for 362 persons who visited general hospital for annual health inspection. The health index scores showed significant correlations with age. Based on the regression equation with age, five regions were divided in health index scores to classify personal health grade. The health index scores were found to identify specific diseases such as hypertension and diabetes.

Key words: Health Index, Bio-Check Unit, Physiological Signal, Survey Questionnaire, Personal Health State

1. Introduction

Programs that diagnose and predict personal health state based on human physiological information are being developed followed by the rising health concerns due to the information development and the aging society. Physiological information includes a person's basic physical information such as age, sex, height, weight, and cardiovascular information such as blood pressure, heart rate, and degree of obesity. By analyzing these, an indicator may be presented for disease prediction and health state.

The Framingham study conducted at Boston University in the United States is an example of a study that predicts and diagnoses a particular disease on the basis of physiological information. One example of the Framingham study is a method of predicting heart disease using risk factors associated with heart disease.[1] In order to predict coronary artery disease, it scored risk factors such as blood pressure, total cholesterol, LDL cholesterol, HDL cholesterol, etc, and the survey response on age, diabetes, smoking status, etc. and developed predictors(Framingham Score) for heart disease. Doctors can use the Framingham Score to predict cardiovascular and coronary artery diseases as a reference for patient advisory.

An example of a study that analyzes the health states of people based on multiple physiological information is the home-based health care service system that uses

*Received 28 Feb., 2011 (No. 11-0161)
[DOI: 10.1299/jbse.6.148]

measurement of periodic physiological variables and electronic health surveys researched by Park et al.[2] Targeting those with chronic illness, discharged patients, and normal persons who are concerned with their health, this system was designed to analyze physiological variables such as daily measured electrocardiogram, blood pressure, blood oxygen saturation, blood glucose level, weight and survey response on amount of exercise, food intake, and health. Therefore, the system allows doctors to continually identify health states and detect abnormal conditions. However, in this study, only a medical specialist can remotely analyze and assess the primary measurement data and give advice regarding risks. The present study is different from Park's study in that the we pursue a system that automatically estimates personal health index scores such as cardiovascular index, stress index, etc. from analysis of physiological information including both measurement and survey questionnaire.[3,4]

Meanwhile, techniques are recently being studied for judging cardiovascular aging and stress by utilizing physiological measurement. Takazawa et al. revealed that accelerated photoplethysmograph(APG) waveform, which is the second derivative of the bloodstream volume waveform, has a strong correlation with age and presented a method to determine the degree of vascular aging depending on the shape of the waveform.[5,6] Medical equipment predicting vascular age using this method of classification are being marketed. Meanwhile, a method to predict stress has been studied by measuring the change in heart rate(heart rate variability: HRV) and analyzing it over time domain and frequency domain.[7-10] Woo showed stresses physically experienced are related to HRV and are significantly associated particularly with risk factors of cardiovascular disease.[11] Currently, medical devices that predict stress level using this method are being marketed. The techniques for judging vascular aging and stress mentioned above, have established reliability through series of studies and can be easily measured, so they are utilized in calculating the health index in the current study.[12]

In this study, we aim to analyze personal health states by combining the physiological measurement information related to human cardiovascular system, stress, and obesity level etc., with related clinicopathologic survey responses, and therefore develop four health indices(cardiovascular index, stress index, obesity index, management index) for personal health estimation and management. In order to calculate these indices, weighting factors are set for each item of measurement and survey data. Lee et al. showed that the cardiovascular index and stress index can be used as clinically meaningful health indicators because the correlation coefficient of the cardiovascular index was found to be 0.685 with the doctor's judgment, and the correlation coefficient of stress index was around 0.638 with the stress survey available in the hospital and public health center.[13] The health indices developed in this study will be installed in the bio-check unit to provide personal health scores related to cardiovascular, stress, obesity, etc. and help personal health management.[3,4]

2. Method

2.1 Bio-Check Unit and Calculation of Health Index

A bio-check unit was developed to estimate personal health state through health-related surveys and noninvasive measurement of physiological signals.(Fig. 1) Sensor interfaces were built in the bio-check unit for measuring various physiological signals and user interfaces were achieved through front monitor and speech recognition for a few key commands. As illustrated in Fig.1, blood pressure is measured by wrapping cuffs around the arm and radial pulse is measured by pressing three points of the wrist in the module located in the left wing of the unit. PPG, EKG, and body fat percentage are measured by grasping handles in the left and right sides of the unit. The unit has function of health index calculation. Recorded data is stored for future use.

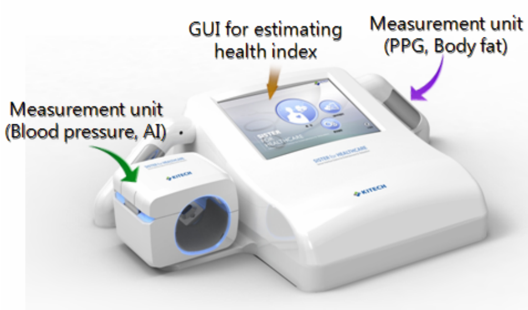


Fig. 1 Bio-check unit

Four health-related indices(cardiovascular index, stress index, obesity index, and management index) were defined to evaluate personal health state. When obtaining each index, the measurement information and survey information are combined to calculate a score as shown in Fig. 2. However, considering the distinct properties of the indices, obesity index is obtained solely through measurement information, and management index solely through survey information.

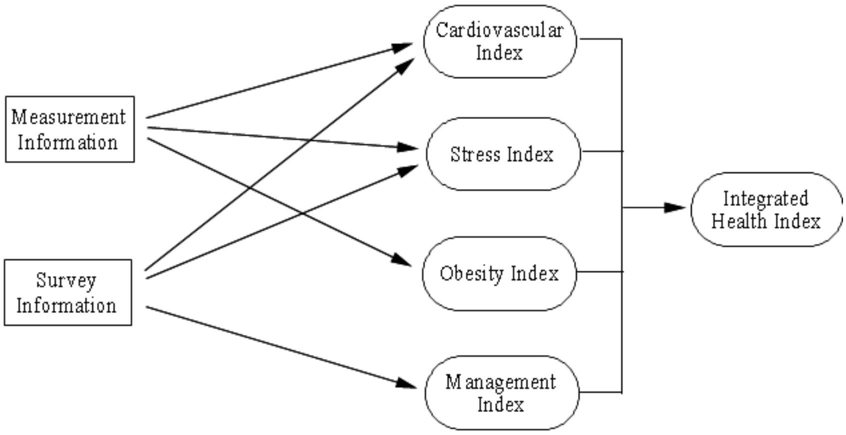


Fig. 2 Health index estimation

For the measurement information, appropriate signals for each index are measured, and the measured signals are scored depending on the extent of deviation from normal values. A weighting factor is given to each signal to obtain a 100-point scale for the measurement score. For the survey information, a set of appropriate questions is made for each index and a weight is given to obtain a 100-point scale for the survey score. Cardiovascular index and stress index are calculated by combining 50% of measurement score with 50% of survey score. As mentioned above, obesity index is calculated solely through measurement and management index solely through survey. Formulas for calculating the four health indices are expressed in Eqs. (1)~(4).

$$\text{Cardiovascular index} = 0.5*\text{measurement score} + 0.5*\text{survey score} \quad (1)$$
$$\text{Stress index} = 0.5*\text{measurement score} + 0.5*\text{survey score} \quad (2)$$
$$\text{Obesity index} = 1.0*\text{measurement score} \quad (3)$$
$$\text{Management index} = 1.0*\text{survey score} \quad (4)$$

The higher score in the health index represents for the better health state. Therefore, when the four health index scores are higher, it means that cardiovascular health is better, stress level is lower, degree of obesity is lower, and health management state is better.

Table 1 illustrates weights of the measurement information for each health index. Scores of the measured physiological signals are lowered, as referred to a study, depending on the extent of deviation from the normal value.[12] The weight of each information is given through the advice of medical specialists.

Table 1 Measurement information and weighting factor for estimating health index

	Blood Pressure	APG (Accelerated Photoplethysmograph)	HRV (Heart Rate Variability)	AI (Augmentation index	BMI (Body Mass Index)	Body Fat Percentage
Cardiovascular Index	60%	15%	15%	10%		
Stress Index			100%			
Obesity Index					50%	50%

The accelerated photoplethysmograph(APG), employed in the cardiovascular index is the second derivative of photoplethysmograph(PPG) which measures the change in radius of finger blood vessel accordingly with pulse wave, and it is known as an indicator for aging of blood vessel.[5,6] The augmentation index(AI) measures pulse strength and is known as a signal indicating the hardening of blood vessels. The heart rate variability(HRV) score, is calculated by giving the two elements of the frequency spectrum analysis, the LF(low frequency component) which is the integral value of the low frequency region and HF(high frequency component) which is the integral value of the high frequency region, a weight of 67% and 33% respectively.[12] As for the obesity index, the body mass index(BMI) evaluates external obesity through the adequacy of height against weight, and the body fat percentage evaluates internal obesity through the fat and muscle ratio.

For the survey information, as summarized in table 2, a set of questions is made for cardiovascular, stress, and management indices, and scored applying appropriate weights. Table 3, 4, and 5 list the survey items used in the cardiovascular index, stress index, and management index. The utilized set of questions and weight are constructed through literature survey and detailed inspection with medical specialists. For cardiovascular index, questions such as case history, symptom, and management state, etc. are combined, and given different weights according to their importance. In the case of stress index, the stress surveys being used in clinical are classified into physical, behavioral, psychological/emotional and reconstructed into 20 questions with identical weights. In management index, seven questions related to application of daily health habits such as smoking, drinking, exercise, eating, sleeping, weight control, etc., also known as Alameda7, are given identical weights.[14] The Alameda7 score employed in the present study has been reported to have a close connection with human remaining life span.

Table 2 Summary of questionnaire information for estimating health index

	Number of Questions	Note
Cardiovascular Index	10	case history, daily life symptom, management state
Stress Index	20	physical, behavior, psychological/emotional state
Management Index	7	life style and eating habits related to remaining life span

Table 3 Questionnaire items used in cardiovascular index

No.	Survey Content	Weight	Classification
1	Do you have heart disease such as angina pectoris or cardiac infarction?	15	Case history
2	Do you have diabetes?	25	Case history
3	Do you have hyperlipemia?	15	Case history
4	Obesity (waist size: male above 35.5 inch, female: above 31.5 inch)	15	management
5	Do you smoke?	5	management
6	Do not drink alcohol often or do not drink alcohol at all.	5	management
7	Heart throb occasionally and pulse is uneven.	5	symptom
8	Is short of breath after moving a little or climbing just one story	5	symptom
9	Often wake up in the middle of a sleep due to shortness of breath	5	symptom
10	Often feel numbness of arm and leg	5	symptom

Table 4 Questionnaire items used in stress index

No.	Survey Content	Weight	Classification
1	Feel flushed (face reddens or becomes hot)	5	physical
2	Stomach feels bloated (experience indigestion)	5	physical
3	Has migraine	5	physical
4	Neck or shoulder often feels locked	5	physical
5	Feel easily fatigued	5	physical
6	Feel tightness of chest	5	physical
7	Sigh involuntarily	5	physical
8	Unable to sleep restfully because of anxiety and worry	5	behavior
9	Increase in objection, complaint, or talk back	5	behavior
10	Constantly unable to concentrate and work efficiency drops	5	behavior
11	Do not eat well due to loss of appetite or suddenly binge eat	5	behavior
12	Feel burdened and wish to avoid meeting people	5	behavior
13	Easily angered and mood swings are extreme	5	Psychology/ emotion
14	Feel impatient and pressed with work	5	Psychology/ emotion
15	Depressed and easily become gloomy	5	Psychology/ emotion
16	Loosing trust with oneself	5	Psychology/ emotion
17	Feel mentally clear and clean.	5	Psychology/ emotion
18	I think I can solve problems that approach me	5	Psychology/ emotion

19	Feel happy all things considered.	5	Psychology/ emotion
20	I think I am managing myself well.	5	Psychology/ emotion

Table 5 Questionnaire items used in management index

No.	Survey Content	Weight
1	Sleep 7~8 hours a day	14.3
2	Daily eat breakfast.	14.3
3	Do not eat snack/midnight snack	14.3
4	Maintain proper weight. (male: between 5% below to 19.9% above ideal weight, female: between 5% below to 9.9% above ideal weight} : ideal weight = (height-100)*0.9	14.3
5	Exercise regularly (more than 3 times a week)	14.3
6	Do not drink alcohol often or do not drink alcohol at all	14.3
7	Do not smoke	14.3

2.2 Clinical Study of Health Index

In order to observe the developed health index score and its change with age, a clinical study was executed for approximately 5 weeks in Sunlin General Hospital Health Promotion Center located in Pohang City in Korea. Among those who came for physical examinations, volunteers were selected and requested to answer survey questions for this study and then measured with medical equipments. The examination time zone was before lunch time which was from 10:30AM to 1:30PM, and those without an empty stomach or drank alcohol the day before were excluded from examination subjects. Since the bio-check unit was under development at the time of conducting the clinical trial, commercial medical devices were utilized for measuring physiological variables. Canopy7 from IEMBIO Inc. was utilized for measuring HRV and APG. DMP-300 of Daeyo medical inc. was employed for measuring and analyzing AI, and IOI-353 of Jawon medical inc. for measuring body fat percentage.

A total of 364 people participated in the clinical study, and the data of 362 participants, excluding 2, were analyzed. Table 6 shows the number of male and female subjects per age group. The number of subjects in each age group exceeded an average number of thirty per sex, and the average age of subjects was about 44.0 for male and 45.4 for female.

Table 6 Number of male and female subjects per age group

Age Group	Female	Male	Total
20s’	36	34	70
30s’	35	33	68
40s’	41	31	72
50s’	53	36	89
above 60	36	27	63
Total	201	161	362

3. Results

Regression analysis of each health index was performed by using SPSS statistics program on the clinical study data. Using the regression equation of each health index with age, personal health states were classified into 5 classes. Moreover, the health indices were tested whether hypertension and diabetes can be identified.

3.1 Classification of Health Index Score

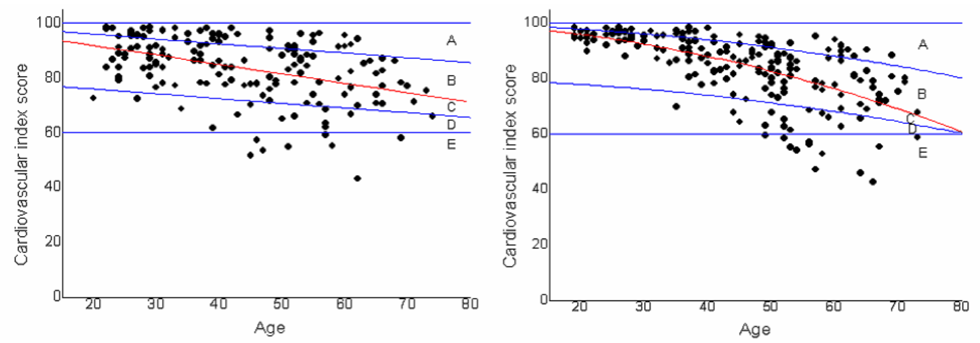
The regression equation of the health index distribution with age tells age-dependent change of the index. Distributions of the four health index scores and regression graphs are illustrated from Fig. 3 to Fig. 6, and five regions are divided for classification of the health state. For example, taking a look at the cardiovascular index score distribution of male subjects in Fig. 3, health classes can be divided into five regions centered on the average line which is the regression curve. The upper portion of the regression curve is class A, B and the lower portion belongs to class C, D, and E. The boundary line dividing class A and B is the line bisecting regression equation and a full score of 100. The boundary line dividing C and D is the line bisecting regression equation and the lowest score line. The lowest score line is defined as scores distributed around the bottom 5%, and region below this is defined as class E.

In the case of cardiovascular index shown in Fig. 3, male's regression equation is presented as a straight line and female's as a parabolic curve. This is because female cardiovascular index shows very high scores in the 20's and 30's, but starts to show a sharp drop from the 40's. The age correlation coefficient is -0.418 in male and -0.614 in female, and thus a stronger correlation is found in female with a shaper drop with age. As for stress index, we did not distinguish male and female because the they are judged to have no difference in clinical sense. As shown in Fig.4, the slope of stress index is -0.191 with a correlation coefficient of -0.262, which are much smaller than those of the cardiovascular index. Obesity index, shown in Fig. 5, is similar with cardiovascular index in that larger slope and correlation coefficient are observed in the female subjects. In Fig. 6, the age correlation coefficient of management index shows positive slope in contrary to other health indices and shows a small correlation coefficient of 0.177.

The integrated health index is calculated in eq.(5) with the reciprocal of the standard deviation of each health index as weighting factor,

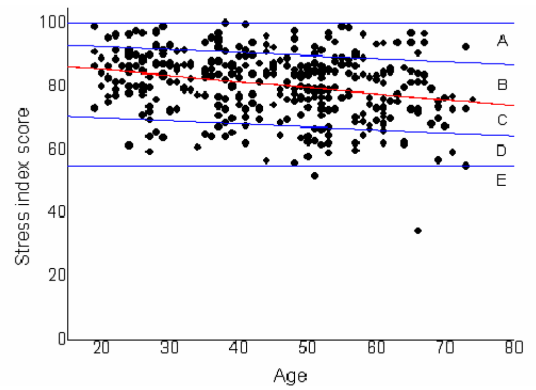
$$\text{Integrated Health Index} = 0.29*\text{Cardiovascular Index} + 0.33*\text{Stress Index} + 0.18*\text{Obesity Index} + 0.20*\text{Management Index} \qquad (5)$$

Fig. 7 shows distributions of the integrated health index score and regression equations together. For male, regression equation has a correlation coefficient(R) of 0.229, and R of 0.481 for female, and therefore female shows age correlation more than two times higher with approximately two times larger slope in the decrease of regression curve. As a result, the integrated health index of female is higher than that of male before the age of 44.7, but becomes lower afterwards.



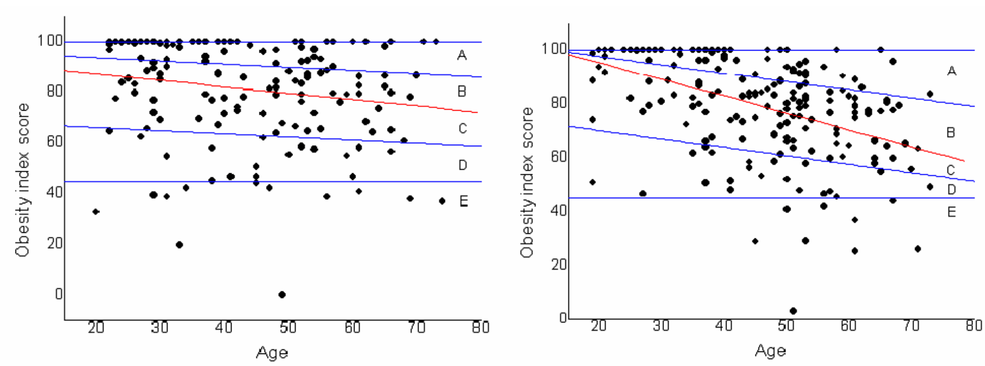
(a) Male: 98.8-0.344*Age (R=-0.418)   (b) Female: $100-0.108*Age-0.00479*Age^2$ (R=-0.614)

Fig. 3 Regression equation and classification of five regions for cardiovascular index



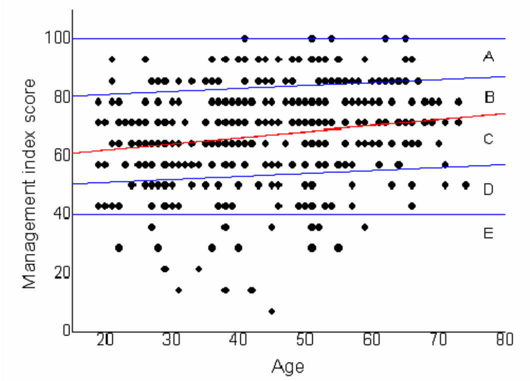
89.2-0.191*Age (R=-0.262)

Fig. 4 Regression equation and classification of five regions for stress index



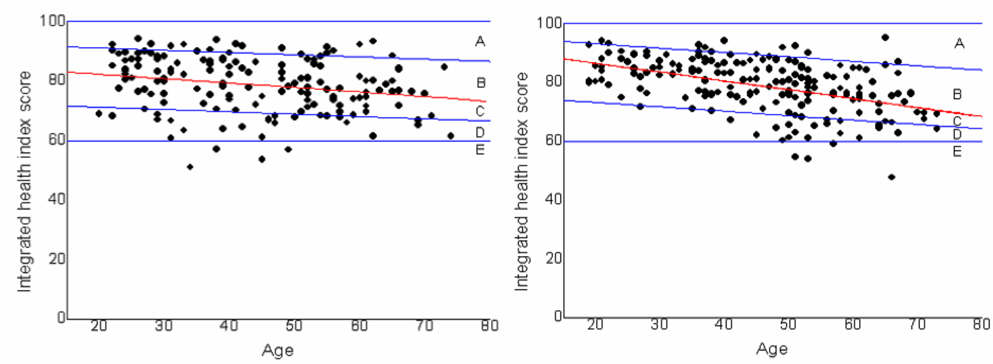
(a) Male: 92.2-0.251*Age (R=-0.174)   (b) Female: 107.8-0.625*Age(R=-0.469)

Fig. 5 Regression equation and classification of five regions for obesity index



57.9-0.210*Age (R=0.177)

Fig. 6 Regression equation and classification of five regions for management index



(a) Male: 85.5-0.152*Age (R=-0.229) (b) Female: 92.6-0.301*Age (R=-0.481)

Fig. 7 Regression equation and classification of five regions for integrated health index

3.2 Health Index for Identifying Illness

Table 7 shows the average and standard deviation of each health index score depending on the presence of hypertension and diabetes, and the capability of health indices for identifying the two diseases through student t-test. Among 362 male and female subjects, there were 71 hypertensive patients and 30 diabetic patients. P-value below 0.05 means capability of identifying illness. Cardiovascular survey score, measurement score, and total score are all p=0.000, so it is evident that cardiovascular index clearly identifies hypertensive and diabetic patients with larger differences in the score. Likewise, stress measurement score is p=0.000 with 10 and 15 point differences in the score in the presence of hypertension and diabetes respectively. Stress survey score gives p=0.279 for hypertension and p=0.148 for diabetes, so it is unable to identify the two diseases. Stress index that combined stress survey and measurement is p=0.014 and p=0.040, demonstrating that hypertension and diabetes can be identified by the index. For obesity index, it shows a 10.5 point higher score(p=0.000) in presence of hypertension demonstrating that obesity significantly influences hypertension. Management index shows a 7.3 point higher score(p=0.010) in presence of diabetes demonstrating that diabetic patients are doing much better in health management. The integrated health index which combined all four index scores shows a 8 point lower score in presence of hypertension, and 6.4 point lower score in presence of diabetes, and demonstrates that it clearly identifies the two diseases.

Table 7 Capability of health indices for identifying diseases

Health Index	Classification	Hypertension			Diabetes		
		Present (N = 71)	None (N = 291)	p-value	Present (N = 30)	None (N = 332)	p-value
Cardiovascular Index	Survey score	79.2 ±17.2	90.6 ±11.1	0.000	61.8 ±18.8	90.8 ±9.6	0.000
	Measurement score	60.3 ±17.4	84.4 ±10.7	0.000	69.9 ±14.8	80.5 ±15.4	0.001
	Total score	69.7 ±12.0	87.5 ±8.70	0.000	65.8 ±11.5	85.7 ±10.4	0.000
Stress Index	Survey score	77.4 ±16.4	75.0 ±16.9	0.279	80.3 ±18.7	75.0 ±16.6	0.148
	Measurement score	78.1 ±15.3	87.8 ±11.5	0.000	73.8 ±17.0	87.0 ±11.9	0.000
	Total score	77.7 ±11.3	81.4 ±9.8	0.014	77.0± 13.9	81.0 ±9.8	0.040
Obesity Index	BMI score	81.5 ±16.8	88.5 ±17.6	0.002	86.1 ±15.8	87.2 ±17.8	0.715
	Body fat percentage score	62.0 ±23.1	76.1 ±23.6	0.000	67.5 ±26.9	73.9 ±23.8	0.219
	Total score	71.8 ±18.1	82.3 ±19.1	0.000	76.8 ±20.6	80.5 ±19.2	0.345
Management Index	Total Score	68.7 ±16.9	67.0 ±16.6	0.446	74.0 ±13.8	66.7 ±16.8	0.010
Integrated Health Index	Total Score	72.4 ±8.6	80.4 ±8.4	0.000	73.0 ±10.3	79.4 ±8.7	0.002

4. Discussion and Conclusion

A bio-check unit and health index were developed to estimate personal health state through surveys and noninvasive measurement of physiological signals. Sensor interfaces were built in the bio-check unit for measuring various physiological signals and user interfaces were achieved through front monitor and speech recognition for a few key commands. We obtained distributions of health index scores through clinical trial, and attempted to classify personal health grade. The clinical trial was conducted for 362 volunteers among the general public who came to the general hospital for annual health inspection, and the average age was 44.7 years old.

In the clinical study for evaluating the effectiveness of the health index, conducted parallel with the present study, Lee et al. verified that the cardiovascular index and doctor's judgment score for cardiovascular health showed a correlation coefficient of 0.685, and the stress index and survey of public health center showed a correlation coefficient of 0.638.[13] Because a correlation coefficient from 0.3 to 0.7 means a clear correlation and a correlation coefficient above 0.7 means a strong correlation, we can see that the cardiovascular index and stress index developed in this study are close to having a strong correlation with cardiovascular health and stress level. For obesity index, external obesity is evaluated through BMI and internal obesity through body fat percentage. Therefore, the obesity index reflects both internal and external obesities. Management index evaluates health management state which is closely related to the remaining life span through questions related to human daily life style and health practices known as Alameda 7.[14]

Distributions of the health index score calculated from the result of the clinical trial were approximated with the regression equation of age, so a change in health index score along with age was observed. Depending on the type of health index and sex, great differences were observed in the slope and the age correlation coefficient of the regression curve. For the cardiovascular index and obesity index, it was found that there were more drastic drops with age for female. Much larger values were observed among female not only in the slope but also in the correlation coefficient, so change in health state with age was more apparent among female.

We were able to classify health index score into 5 classes using age regression equation and lowest score line. With regression equation as the reference, score region above it is given class A, B, score region below it is given class C, D, and region below the lowest score line receives class E. We tried to divide the classes considering the standard deviation of the score, but because distributions of health index score didn't show a normal distribution which made it difficult to classify, we used the method mentioned above. Considering physiological differences between male and female, we analyzed the cardiovascular index and obesity index separately depending on sex, but did not distinguished sex in the stress index and management index. Health index program users can receive health advice by checking their classes in the four health indices and integrated health index. For example, if the integrated health index score of a 50 year old male is calculated as 83.5, the class is B and the health state is good because the score is higher than the average value of 78.6 of the 50 year old male as can be calculated from the regression equation of the integrated health index.

The developed health index scores showed significant differences depending on the presence of hypertension and diabetes. Cardiovascular index score was 18 point lower in presence of hypertension, and about 20 point lower in presence of diabetes and therefore the two diseases can be clearly distinguished. Stress index score was about 4 point lower in presence of hypertension or diabetes, so the two diseases are judged to be somewhat distinguishable. Obesity index score of hypertensive patients was 10.5 point higher and management index of diabetic patients was 7.3 point higher. Therefore, it is judged that by analyzing health index scores, the possibility of a risk for a particular disease can be warned.

The bio-check unit was developed to evaluate health scores and help to manage personal health state through analysis of measured physiological signals and answers to survey questions. The physiological signals employed the present study were restricted to easily measurable and noninvasive ones. In order to overcome this limitation, survey questions were given on items such as diabetes, hyperlipemia, which could be accurately decided through doctor's diagnosis based on blood test. We believe accurate estimation of the personal health state will be possible only through various medical tests including invasive measurement and doctor's decision. Furthermore, the statistical analysis of the present study was conducted to 362 subjects, and hence, data need to be continuously accumulated for more accurate decision on the classification of health grade.

Acknowledgments

This work was funded by the next generation growth engine project supported by the Korean Ministry of Knowledge Economy under grant No.10029012009-22 that had been supervised by KITECH with a title of Health Robot Common Interface Application Technology Development.

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