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Parameters Characterizing Nature of Personal Health in the Correlation between Energy Expenditure/Supply and Body- Fat*

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***Abstract*— Correlations between energy expenditure/supply and body-fat percentage were studied using personally stored daily time-series data. The weighting patterns for the summation of daily time-series energy expenditure and supply data giving the maximum correlations with the variation of daily body-fat percentage data were obtained. The weighting patterns can be expressed by two parameters whose combination is considered to characterize the nature of personal health. The combination of the parameters for a subject was found to show a significant bias in the frequency distribution, independent of season and aging, for the term of seven years, and the combination of the parameters of 20 other subjects showed a tendency to divide into two types.**

I. Introduction

Application of the Internet to healthcare, such as in m-health and p-health, are current topics of interest [1]-[3]. In particular, the demand for personalized healthcare systems to help prevent diseases and improve health has been increasing recently [4]. Within this context we have developed a personal dynamic healthcare system (PDHS) utilizing the Internet [5]. It enables time-series of daily- health and lifestyle data to be stored in a database by using a mobile phone. In addition, it can extract personally useful information, such as rules and patterns concerning lifestyles and health conditions embedded in daily time- series of personal health and lifestyle data. We call this 'healthcare- data- mining'.

In the healthcare- data-mining process [6], first we check the correlation between summation of the time-series lifestyle data and variations of the time-series health data. In this study, the weighting patterns for the summation of daily time- series of energy expenditure and supply data giving the maximum correlations to the variation of daily body-fat percentage data were obtained on the basis of personally stored time-series data. We adopted the normal distribution function as a weighting pattern [7]. Two parameters characterizing the weighting pattern are considered to also characterize the nature of personal health.

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II. Materials and Method

A. Analysis Method

The time-series data analysis described here is based on the simple idea that the accumulation of the effects of lifestyle events, such as exercise and ingestion, could affect personal health with some delay [6]. The delay may reflect complex bio-reactions, such as those of metabolism in a human body. In the analysis, the accumulation of the effects of such lifestyle events is represented by the weighted summation of energy expenditure or supply data (calories) due to exercise or ingestion. The accumulation of the effects may cause variation in body-fat percentage, with some delay.

In the analysis, we examine the correlation coefficient, r, described as:

$$r(\Delta h_{nm}, e^{w}{}_{nl}) = \frac{Cov(\Delta h_{nm}, e^{w}{}_{nl})}{SD(\Delta h_{nm}) SD(e^{w}{}_{nl})} \quad . \tag{1}$$

Here,

$$\Delta h_{nm} = h_n - h_m \tag{2}$$

is the difference in the time -series of body-fat percentage data, h, representing the variation of body -fat, and

$$e^{w}{}_{nl} = w(0)e_{n-1} + w(1)e_{n-2} + w(2)e_{n-3} + ... + w(l-1)e_{n-l} \tag{3}$$

is the weighted summation of the time –series of energy expenditure or supply data, e, during a certain period, representing the accumulation of the effects of lifestyle events (Fig.1). In Eq. (1), $SD(\Delta h_{nm})$ and $SD(e^{w}{}_{nl})$ are the standard deviation of Δh_{nm} and e^{w}_{nl}, respectively, and $Cov(\Delta h_{nm}, e^{w}{}_{nl})$ is the covariance.

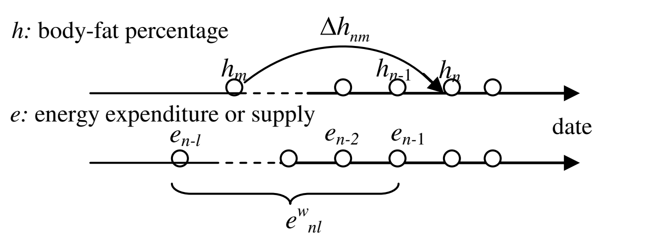

Fig. 1 Reference figure for examining time-series correlation between accumulation of effects of energy expenditure or supply and variation of body-fat percentage.

In Eq. (3), weighting coefficients, $w(0)$ to $w(l\text{-}1)$, are derived from the weighting function

$$w(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\} \quad . \tag{4}$$

Equation (4) is the well-known normal distribution function characterized by two parameters, μ and σ. When we use Eq. (4) as a weighting function in the summation of daily time-series of lifestyle events data, the values of x are 0, 1, 2, …, l-1, and corresponding $w(0)$, $w(1)$, $w(2)$, …, $w(l\text{-}1)$ are assigned as weighting coefficients descending in date [7]. The value of μ is restricted to non-negative when used in the weighting function.

We calculated the correlation coefficient, r, between Δh_{nm} and e_{nl}^{w} on the basis of time-series data to find a suitable weighting pattern characterized by μ and σ so that r becomes its largest. Here, n-m and l are parameters. Weighting patterns for some (μ, σ) sets are shown in Fig. 2.

If r becomes largest for the (a) pattern, accumulation of the effects of quite recent lifestyle events (energy expenditure or supply) affects body -fat without delay. If r becomes largest for the (b) or (d) pattern, accumulation of the effects for a long term affects body -fat. If r becomes largest for the (c) pattern, accumulation of the effects for a short term affects body -fat with some delay.

B. *Time-series Data for Analysis*

Our first point of interest is knowing if the combination of parameters, (μ, σ), giving the maximum correlation depends on the season when the data were obtained, and/or on aging. Thus, first, time-series data of body-fat percentage, energy expenditure due to exercise, and energy supply due to ingestion obtained from a 58-year-old male over about 7 years were analyzed. Second, to investigate the individual differences, time-series data of body- fat and energy expenditure due to exercises obtained from 20 subjects (male: 9, female: 11, average-age: 22) over half a year were analyzed.

Body-fat percentage was measured with a reactance meter (Tanita, Japan). Energy expenditure due to exercise was measured with a wearable monitor (Omron, Japan), and energy supply was estimated from each day's breakfast, lunch and dinner contents referring to foods-calorie tables.

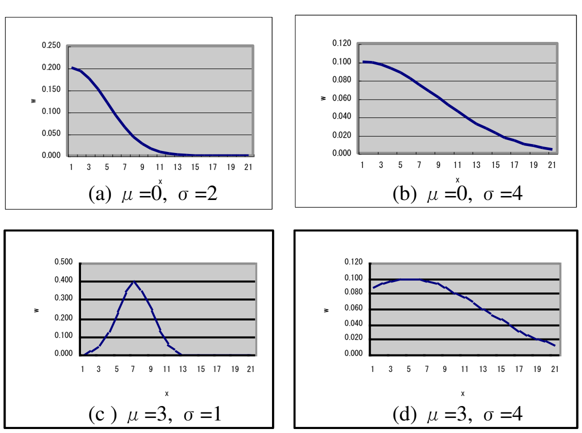

Fig. 2 Weighting patterns for (μ, σ) sets (horizontal: x, vertical: w) [7]

III. Results

A. *Analysis of Seven Years' Data for One Subject*

1) *Correlation between energy expenditure and body-fat*

The weighting pattern used in the analysis was Eq. (4) with combinations of μ = 0, 1, 2, 3, and σ = 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 (32 patterns in total). Here, the value of μ represents the delay, whereas the value of σ represents the period of energy expenditure affecting body -fat. The weighting coefficients derived from Eq. (4), $w(0)$ to $w(10)$, here l = 11, were normalized as follows:

$$\sum_{i=0}^{10} w(i) = 1 . \tag{5}$$

The correlation coefficient, r, was calculated on the basis of daily time-series data of energy expenditure and body-fat percentage during the term from 06/01/2004 to08/31/2011 for a subject (58-year-old male). The calculation was performed on the time-series data every three months (a season). The combination of parameters, (μ, σ), giving the maximum correlation between the weighted summation of energy expenditure and the variation of body-fat percentage is summarized in Table 1 along with the maximum value of r. When the maximum value of r is less than 0.2, "null" is inserted into the (μ, σ) column.

The frequency distribution of the combination of parameters giving the maximum correlation is shown in Fig. 3. The combinations are scattered, independent of season and aging. However, the distribution shows a significant bias, that is, the combination of μ = 1, 2 and σ = 0.5, 1.0 is dominant (the ratio to the total number of combinations : 16/27 (60%)).

TABLE 1. COMBINATION OF PARAMETERS GIVING MAXIMUM CORRELATION BETWEEN WEIGHTED SUMMATION OF ENERGY EXPENDITURE AND BODY-FAT FOR A SUBJECT

Term	(μ, σ)	r	Term	(μ, σ)	r	Term	(μ, σ)	r
6/1/04-8/31/04	(1, 0.5)	-0.403	6/1/05-8/31/05	(1, 0.5)	-0.253	6/1/06-8/31/06	(3, 2.5)	-0.343
9/1/04-11/30/04	(3, 1)	-0.341	9/1/05-11/30/05	(3, 1.5)	-0.463	9/1/06-11/30/06	(1, 0.5)	-0.216
12/1/04-2/28/05	(2, 1)	-0.329	12/1/05-2/28/05	(2, 4)	-0.462	12/1/06-2/28/07	(1, 0.5)	-0.315
3/1/05-5/31/05	(2, 1)	-0.482	3/1/06-5/31/06	(2, 0.5)	-0.272	3/1/07-5/31/07	(3, 4)	-0.577
Term	(μ, σ)	r	Term	(μ, σ)	r	Term	(μ, σ)	r
6/1/07-8/31/07	(2, 1.5)	-0.474	6/1/08-8/31/08	(3, 3.5)	-0.369	6/1/09-8/31/09	(3, 1.5)	-0.346
9/1/07-11/30/07	(0, 1)	-0.2	9/1/08-11/30/08	(2, 1)	-0.479	9/1/09-11/30/09	(3, 1.5)	-0.482
12/1/07-2/28/08	(1, 0.5)	-0.2	12/1/08-2/28/09	(2, 0.5)	-0.359	12/1/09-2/28/10	null	
3/1/08-5/31/08	(1, 1)	-0.509	3/1/09-5/31/09	(1, 1)	-0.336	3/1/10-5/31/10	(1, 0.5)	-0.291
Term	(μ, σ)	r	Term	(μ, σ)	r			
6/1/10-8/31/10	(1, 0.5)	-0.261	6/1/11-8/31/11	(2, 1.5)	-0.42			
9/1/10-11/30/10	(2, 0.5)	-0.31						
12/1/10-2/28/11	null							
3/1/11-5/31/11	(2, 0.5)	-0.349						

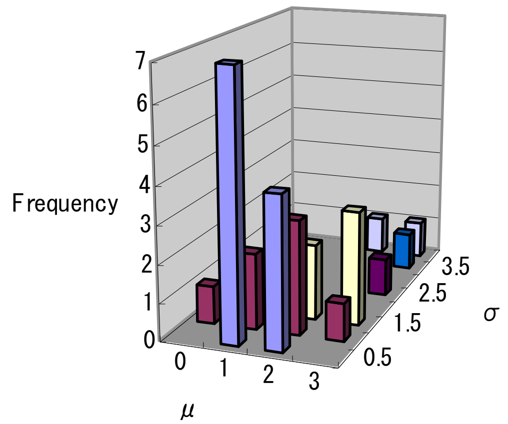

Fig. 3 Frequency distribution of combination of parameters (μ , σ) giving maximum correlation between weighted summation of energy expenditure and body- fat for a subject. (μ , σ) was evaluated from the time-series data every three months (a season) for the term of seven years (n = 27).

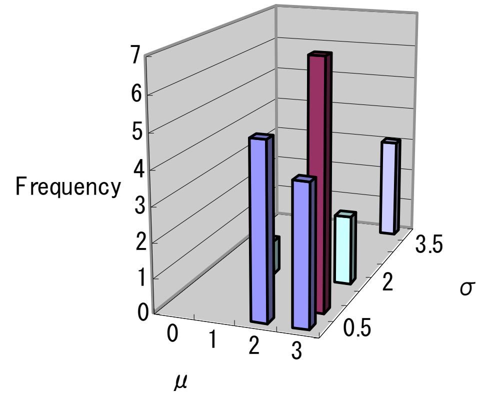

Fig. 4 Frequency distribution of combination of parameters (μ , σ) giving maximum correlation between weighted summation of energy supply and body -fat for a subject. (μ , σ) was evaluated from the time-series data every three months (a season) for the term of seven years (n = 22).

2) *Correlation between energy supply and body -fat*

The correlation coefficient, *r*, was calculated on the basis of daily time-series data of energy supply and body-fat percentage during the term from 2004/06/01 to 2011/05/31 for the same subject. The calculation was performed on the time-series data every three months (a season). The weighting pattern used in the analysis was also Eq. (4), with combinations of μ = 0, 1, 2, 3, and σ = 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 (32 patterns in total). The combination of parameters, (μ , σ), giving the maximum correlation between the weighted summation of energy supply and the variation of body-fat percentage is summarized in Table 2 along with the maximum value of *r*. When the maximum value of *r* is less than 0.2, "null" is inserted into the (μ , σ) column.

The frequency distribution of the combination of parameters giving the maximum correlation is shown in Fig. 4. The combinations are scattered, independent of season and aging. However, the distribution shows a significant bias, that is, the combination of μ = 2, 3 and σ = 0.5, 1.0 is dominant (the ratio to the total number of combinations : 16/22 (73%)).

TABLE 2. COMBINATION OF PARAMETERS GIVING MAXIMUM CORRELATION BETWEEN WEIGHTED SUMMATION OF ENERGY SUPPLY AND BODY-FAT FOR A SUBJECT

Term	(μ , σ)	*r*	Term	(μ , σ)	*r*	Term	(μ , σ)	*r*
6/1/04-8/31/04	(3, 0.5)	0.496	6/1/05-8/31/05	(3, 1)	0.31	6/1/06-8/31/06	(3, 0.5)	0.305
9/1/04-11/30/04	(3, 1)	0.328	9/1/05-11/30/05	(3, 2)	0.501	9/1/06-11/30/06	(2, 0.5)	0.322
12/1/04-2/28/05	(3, 0.5)	0.312	12/1/05-2/28/06	(3, 4)	0.305	12/1/06-2/28/07	(3, 0.5)	0.226
3/1/05-5/31/05	(3, 2)	0.4	3/1/06-5/31/06	(3, 1)	0.236	3/1/07-5/31/07	(3, 1)	0.279
Term	(μ , σ)	*r*	Term	(μ , σ)	*r*	Term	(μ , σ)	*r*
6/1/07-8/31/07	(2, 0.5)	0.335	6/1/08-8/31/08	(3, 1)	0.416	6/1/09-8/31/09	null	
9/1/07-11/30/07	(3, 1)	0.453	9/1/08-11/30/08	(2, 0.5)	0.315	9/1/09-11/30/09	null	
12/1/07-2/28/08	null		12/1/08-2/28/09	(2, 0.5)	0.309	12/1/09-2/28/10	null	
3/1/08-5/31/08	(1, 2)	0.439	3/1/09-5/31/09	(3, 4)	0.44	3/1/10-5/31/10	null	
Term	(μ , σ)	*r*						
6/1/10-8/31/10	null							
9/1/10-11/30/10	(3, 1)	0.36						
12/1/10-2/28/11	(1, 4)	0.351						
3/1/11-5/31/11	(3, 4)	0.443						

B. *Analysis of Half a Year's Data for Twenty Subjects*

The correlation coefficient, *r*, was calculated on the basis of daily time-series data of energy expenditure and body-fat percentage during the term of 06/01 to 08/31 (summer) and 09/01 to 11/30 (autumn) for twenty subjects (male: 9, female: 11, average- age: 22). The weighting pattern used in the analysis was Eq. (4), with combinations of μ = 0, 0.5, 1.0, 1.5, …, 4.0 and σ = 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 (72 patterns in total). To investigate the individual differences, here, the total number of weighting patterns evaluated was increased.

The frequency distribution of the combination of parameters giving the maximum correlation is shown in Fig. 5. An interesting thing is that the combination of parameters seemed to be divided into two types, that is, one with small μ and σ , and the other with large μ and widely distributed σ .

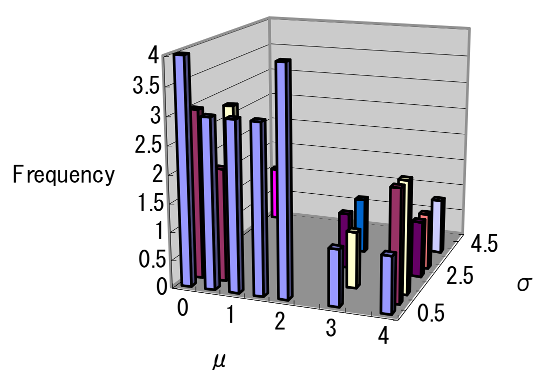

Fig. 5 Frequency distribution of combination of parameters (μ , σ) giving maximum correlation between weighted summation of energy expenditure and body -fat for 20 subjects. (μ , σ) was evaluated from the time-series data during summer (06/01 to 08/31) and autumn (09/01 to 11/30) (n = 40).

IV. Discussion

We studied the time-series correlation between energy expenditure/supply and the body-fat percentage of a person based on a supposition that the weighting pattern for the summation of daily time- series of energy expenditure or supply data giving the maximum correlation to the variation of daily body-fat data characterizes the nature of personal health. In the analysis, the weighting pattern can be expressed by two parameters, μ and σ, due to the use of the well-known normal distribution function for weighting. That is, the combination of parameters, (μ, σ), giving the maximum correlation to the variation of body- fat is considered to characterize the nature of personal health.

Although we had expected that the combination (μ, σ) giving the maximum correlation would depend on the season or aging, it was scattered, independent of season and aging, for the term of seven years for a subject, as shown in Tables 1 and 2. The (μ, σ) was evaluated from the time-series data every three months (a season). The reason the scattering occurs may be the influence of lifestyle factors other than exercise and ingestion over those seven years. Note, however, that the frequency distributions of (μ, σ) show a significant bias, as seen in Figs. 3 and 4. The bias was more significant in the frequency distribution of (μ, σ) related to the correlation between the weighted summation of energy supply and body -fat.

We suppose that the bias represents the nature of personal health in the correlation between energy expenditure/supply and body-fat for a subject, taking account of the independency of season and aging. That is, the nature of personal health of this subject might be characterized by (1~ 2, 0.5~ 1) for the correlation between energy expenditure and body- fat and (2~ 3, 0.5~ 1) for the correlation between energy supply and body-fat.

The results of analyzing the time-series data of twenty subjects obtained during summer and autumn is more interesting. The frequency distribution of (μ, σ) relating to correlation between the weighted summation of energy expenditure and body- fat implies that the combination of (μ, σ) is divided into two types as shown in Fig. 5. One is with μ = 0~ 2 and small σ (0.5~ 1), while the other is with μ = 3~ 4 and widely distributed σ (0.5~ 4). In this case, also, the distribution of (μ, σ) does not depend on the season (summer or autumn).

Thus, the nature of personal health seems to be clustered into two types, one with low σ, in which a short -term energy expenditure affects body- fat without a long delay, and the other with high μ, in which energy expenditure affects body -fat with a long delay. In the latter type, the term of an accumulation affecting body- fat is widely distributed. Presently, however, this is simply a hypothesis because the number of subjects is small (n = 20). For concrete evidence, further study with a larger number of subjects will be needed.

V. Conclusion

In a previous paper [7], the concept of weighting was introduced for the summation of daily lifestyle data, whose time-series correlation to variations of health data was examined. In this paper, we analyzed time- series of energy expenditure/supply and body-fat percentage data based on the supposition that the weighting pattern for the summation of daily time- series of energy expenditure or supply data giving the maximum correlation to the variation of daily body-fat data characterizes the nature of personal health.

Our results are summarized as follows.

(1) The combination of weighting parameters (μ, σ) giving the maximum correlation to the variation of daily body-fat data shows a significant bias in the frequency distribution, independent of season and aging, for the term of seven years for a subject.

(2) The dominant combinations (μ, σ) related to the correlation between energy expenditure/supply and body- fat may represent the nature of the personal health of this subject.

(3) The nature of personal health seems to be clustered into two types, one with low σ, in which a short -term energy expenditure affects body- fat without a long delay, and the other with high μ, in which energy expenditure affects body-fat with a long delay.

At the present time, however, this conclusion is simply a hypothesis because the number of subjects is small. For concrete evidence, further study on a larger number of subjects will be needed.

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