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ESTIMATION METHOD FOR CONSUMPTION ENERGY FOR HUMANS IN DAILY CYCLE

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Abstract – Estimation method of consumption energy for human daily cycle was studied using triple axes attached on the sternum [1]. It is important to estimate the posture and movement in order to get reliable values of consumption of energy. Consumption of energy for various postures and movements was obtained in relation to consumption of oxygen during respiration. In our 24 hour daily cycle, the most common postures and movements are walking, running, standing still, standing with a little movement, sitting still, reclining, and sleeping. And consumption of energy for our living depends on the type of movement. Consumption of energy for human movement is varied, but appropriate data could be obtained by accelerometer to estimate consumption of energy. Additionally, type of movement and consumption of energy could be shown to have a correlation.

Keywords: consumption energy, posture, movement

1. INTRODUCTION

A new physical examination regulation started in Japan in 2008 that is mandatory for people who are more than 40 years old. This system is to help prevent life style related diseases to decrease medical costs nationwide. Therefore it is important for people to keep appropriate body-mass index (BMI). In order to maintain a suitable BMI, consumption energy has to be estimated for the daily 24 hour cycle. There are previous studies for estimating consumption energy [2,3,4]. But the previous studies did not consider the various movements humans make throughout the day, and therefore this study takes a variety of movements into consideration. Consumption energy depends on posture and movement, therefore posture and movement for living have to be estimated appropriately. The most frequent postures and movements are walking, running, standing still, standing with a little movement, sitting still, reclining, and sleeping.

This study estimates the consumption of energy by the postures and movements in the daily cycle by the quantity of oxygen uptake, and the carbon dioxide excretion in the breath. At same time the strength of movement is measured.

2. METHOD

A lightweight accelerometer with triple axes on an IC chip was installed on the sternum as shown in Fig. 1. The direction progress was defined as the X-axis, and transverse to the direction of progress was defined as the Y-axis, and direction of gravity was defined as the Z-axis, respectively. The data from the Z-axis 1.0 G during standing still at rest, the data from both the X-axis and the Y-axis should be 0 G. Consumption energy depends on posture and movement, therefore postures and movements have to be estimated first and then the consumption of energy is estimated for each posture and movement. Human posture and movement is very complicated, but it can be calculated using the data from the accelerometer.

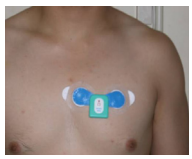

Fig. 1. IC chip on the sternum for defining axes

2.1. Estimation of posture and movement

The data that was obtained by the accelerometer was compensated for in angle direction of gravity. The progressive and transversal directions were not compensated because there was no baseline. Fig. 2. shows typical average movement data from the accelerometer, processed by 512 data point segments that were sampled at 0.01 second increments. Typical data obtained by accelerometer is shown in Fig. 2.

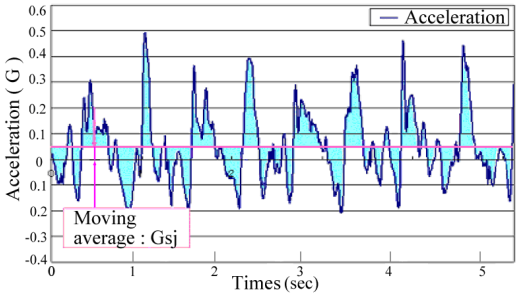

Fig. 2. Obtained data by accelerometer

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The moving average, or G_{sj}, shows the data sampled at 0.01 seconds and processed by average movement. The values show the angle of inclination of the body. The data that were obtained from the accelerometer were also processed by FFT in order to get the peak values for the specific frequency for each movement of the body. Typical data processed by FFT is shown in Fig. 3.

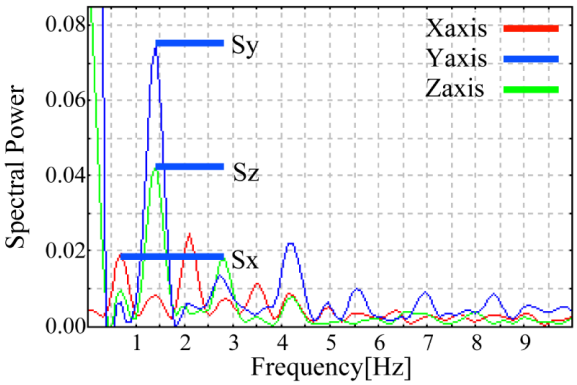

Fig. 3. FFT processed results of the obtained data

The walking cadence is 2 steps per second. The peak values processed by FFT are Sz for the direction of gravity, Sx for the progressive direction, and Sy for the transversal direction, respectively. The frequency of Sy was decided at 1/2 of Sz and Sx, because the frequency of Sy and Sz accorded with the steps, but Sy accorded with twist frequency. Also the movement data from the accelerometer was sampled at 0.01 second increments as moving average. Values for body angle were estimated for standing and reclining positions. The values were estimated as shown in Equation (1).

$$G_{sj}=\left(\sum_{i=1}^{512}(G_{sj}(i))\right)/512 \qquad (1)$$

where G_{sj} is the moving average for each axis.

The procedure for estimating posture and movement were as follows:

(1) Discrimination of dynamic and static states.

Dynamic and static states were discriminated by using values of Sz. Values lager than the threshold value were determined as dynamic, values below the threshold were determined as static.

(a) If the values were determined dynamic, that movement was walking or running.

Fig. 4. shows the threshold of dynamic and static states. There were plenty of values for dynamic and static measurements for Sz, as shown in Fig. 4.

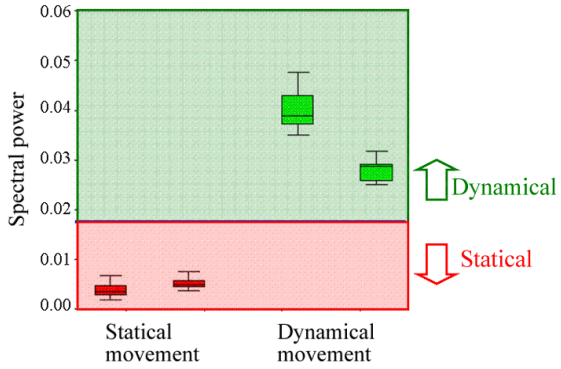

Fig. 4. The strength of spectral power for Sz

(b) Values larger than the threshold level are determined as walking, below the threshold is determined as running, as shown in Fig. 5. Sz was larger for running than for walking.

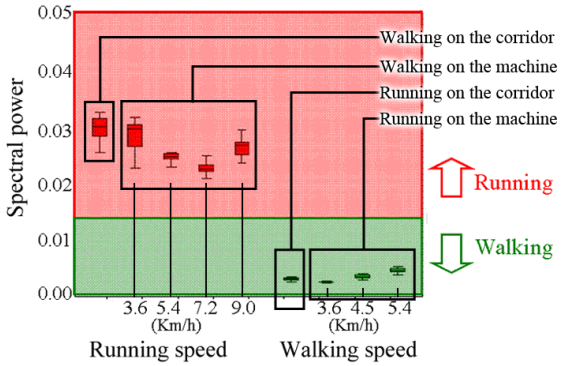

Fig. 5. Discrimination for walking and running movement

(2) Discrimination of standing still, sitting still, and reclining

For static state estimations, there were two positions, standing and reclining, as shown Fig. 6. Standing and reclining were discriminated by using values of the inclination angle. Measurements included standing with a little movement, standing still and sitting still. In the next step, the values of Sz were compared to the threshold level. If the value was lager than the threshold level, it was determined to be standing still or with a little movement, other cases were considered to be sitting still.

(a) Estimation for upright or reclining

Static estimations were for upright or reclining positions. If the inclination angle was larger than 50 degrees from the vertical position was defined as reclining.

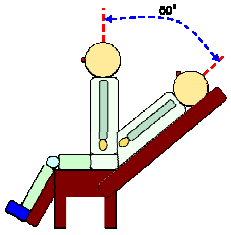

Fig. 6. Definition of the inclination angle of sitting still

(b) Estimation of sitting still and standing still

Although it was hard to estimate values between sitting still and standing still because the measurements were at the sternum, basal energy expenditure could be roughly estimated as the same range, as shown later. However, for standing with a little movement, the consumption of energy had larger values. There were many kinds of standing positions. There were some when the walker is trying to reach a place, but there were other times when the walker was only wandering, This occurs in the human daily cycle, such as walking in the office without a place at which to arrive, or a shopper who is looking for something but does not know where it is. Fig. 7. shows differences between standing still and standing with a little movement, when the Sz becomes larger than sitting still.

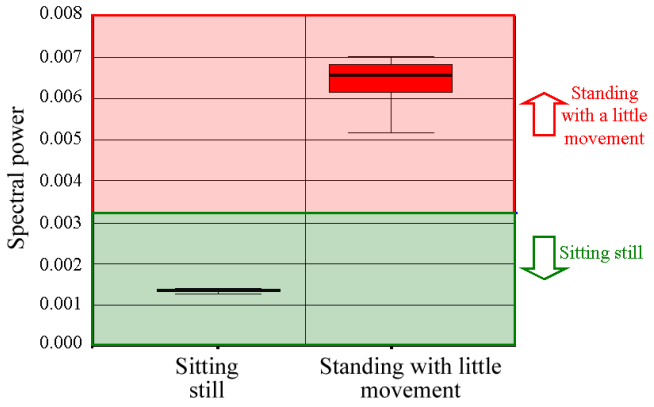

Fig. 7. Discrimination of standing with a little movement and sitting still

To conclude, the procedure for the estimation of postures and movements is shown as a flow chart in Fig. 8, where Sz was the first peak frequency for Z axes processed by FFT, Gsz was the moving average for Z axes, Th1 was the threshold for dynamic or static postures, Th2 was the threshold to discriminate for reclining, and Th3 was the threshold to discriminate for sitting still.

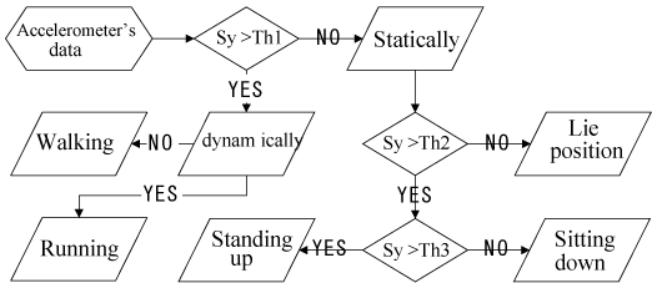

Fig. 8. Flow chart of procedure for discriminating postures and movements

3. RESULT

3.1 Estimation of posture and movement

Fig. 8 shows the results of the estimation for actual posture and movement for horizontal and vertical axes in relation to time, as mentioned above. The participants went through sequences of sitting still in a chair, standing still without moving, walking, standing with a little movement, and after that, walking again. The results show that standing and sitting still could not be discriminated because they were the same values of Gsz. The estimation could be determined, but from time to time it was indeterminable. For example, the participant in Fig. 9 walked between 0.5 minutes and 2 minutes illustrated in pink colored, but around 0.7 minutes he was moving only a little. There were a lot of other reasons, such as walking up stairs, walking down stairs, and so on.

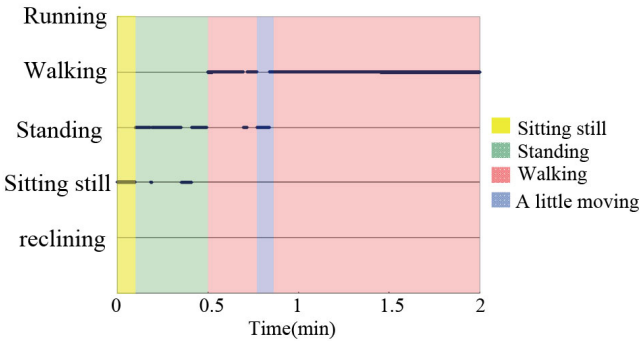

Fig. 9. The result of estimation for posture and movement

3.2 Estimation of consumption energy for daily cycle

There were many kinds of postures in our daily cycle, but mostly they were movements that belong to sleeping, reclining, sitting still, standing still, standing with a little movement, walking, and running. We may have other postures and movements, but they last a short time in the daily cycle. Just to live, our bodies consume energy through basal energy expenditure (BEE). The consumption energy during the daily cycle was estimated through incremental quantities of BEE. Consumption energy was measured by the quantity of oxygen intake and carbon dioxide exhaust. These gases were sampled by a 250 litres accumulation bag. The samples were taken after 4 minutes of warming-up, for 5 to 7 minutes, at the same time of the sampling of the accelerometer data for posture and movement.

(1) Consumption energy during sleeping

Consumption energy BEE is defined by basal energy expenditure during sleeping by the well-known Harris Benedict equation as shown in Equation 2, where BW is bodyweight, Ht is body height and Yr is age, respectively.

For males:

BEE = 66 + (BW x 13.7) + (Ht x 5.0) – (Yr x 6.8)

For females:

BEE = 665 + (BW x 9.6) + (Ht x 1.7) – (Yr x 7.0)

(2) Consumption energy for walking and running

Fig. 10. shows consumption energy for walking. The participants were aged 22 to 26 years old and male. The values were shown without BEE. This shows that consumption energy depends on body weight, the heavier the body, the higher the energy consumed during walking. And Fig.11. shows consumption energy for running without BEE. In this action, the heavier body weight also consumed

more energy. But not enough data could be obtained, therefore the reliability remains uncertain.

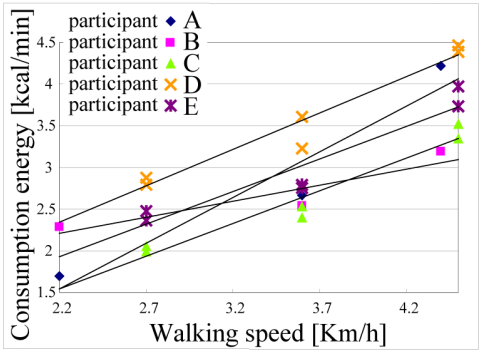

Fig. 10. Consumption energy for walking

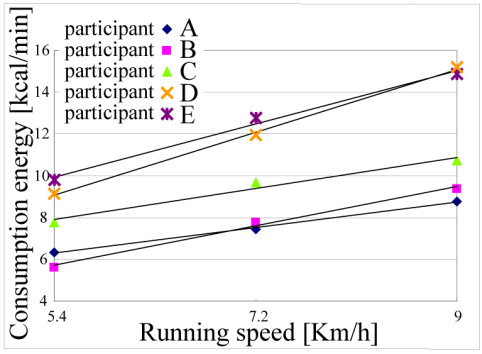

Fig. 11. Consumption energy for running

(3) Dependency on body weight and consumption energy for standing still, standing with a little movement, and sitting still. Consumption energy between standing still and standing with a little movement has different values. On average, less consumption energy was required for standing still than for standing with a little moving, as shown in Fig. 12. There are many common instances of standing with a little movement in the daily cycle, for example, while lingering around a desk in the office, or walking sluggishly while shopping.

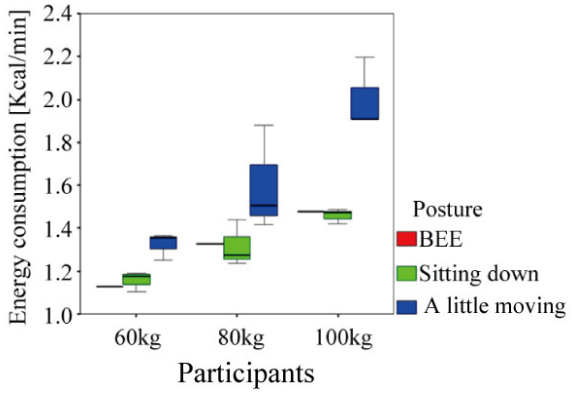

Fig. 12. Dependency of body weight and consumption energy for standing with a little movement, sitting still and BEE

(4) Consumption energy for BEE and reclining

Fig. 13. shows comparison of consumption energy for BEE and reclining. Consumption energy for both was estimated at almost the same range of values. Likewise, standing still yielded similar values. However, standing still with a little movement resulted in BEE. This means that even when in a static state, some quantity of energy is consumed in our body.

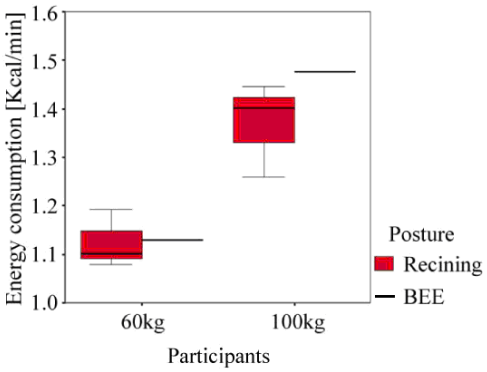

Fig. 13. Comparison of BEE and reclining

4. CONCLUSIONS

Estimation method for consumption energy for the daily cycle of people has been studied with an IC chip attached on the sternum. For estimating consumption energy, posture and movement have to be estimated appropriately. The results of the estimations for this study are as follows:

(1) Estimation method of posture and movement was obtained from an accelerometer and processed by FFT.

(2) Estimation of consumption of energy was processed by FFT from the accelerometer data.

(3) Consumption energy for the daily cycle was estimated but this study should be replicated with a greater number of participants.

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