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Spectral Analysis in Walking Balance by Elderly Subjects

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***Abstract*—Elderly people lose their rhythm of walking balance, because their body alignment and standing balance become less stable through aging. The fluctuations of both hips movement while walking were measured using a portable measurement system with two accelerometers. Before they have had physical exercise and when walking without shoe insoles, the fluctuations of the hip movement, having back and knee pain, was not rhythmic, and also not proportional to 1/f (f=frequency) fluctuation, their walking was unstable. After physical exercise and walking with insoles, their walking became rhythmic and was approximately close to proportional to 1/f fluctuation, and their walking improved. This study provides useful information for the improvement of walking.**

***Index Terms*—Walking balance, AR modeling, *spectral analysis, 1/f* fluctuation**

I. Introduction

THE fluctuation of movement, i.e., the feedback control movement of left and right legs in the walking sequence becomes less stable under the influence of a problematic part of the lower limb or back [1]. Elderly people have begun to exhibit obvious symptoms of this problem. This problem was analyzed on the basis of two approaches. The first approach was an analysis of 1/f fluctuation in walking improvement by physical exercise using a portable measurement system of walking. The portable acceleration system of walking consists of two small, light-weight and synchronized acceleration sensor connected to a micro personal computer. While walking, it was worn on a subject's waist, accelerometers were fixed to the subject's left and right sides of hip (see Fig. 1a, Fig.1b). This system does not cause much discomfort to the subjects. The second approach was an analysis of 1/f fluctuation in walking improvement wearing suitable shoes and shoe insoles by using a portable measurement system of walking.

While walking, the time series data of accelerations of movement were recorded onto a small memory card. However, it was difficult to analyze directly the characteristics of movement stability using the raw serial measurement data, because of their complex fluctuations in feedback control movement among their variables. An analysis of 1/f fluctuation utilizing Auto-Regressive (AR) modeling [2]-[5] was done in walking balance of elderly subjects. They had long and various daily habits in the aging process, therefore each walking balance was not only less stable, but also different. This study suggests that they should understand their own characteristic of walking and make their own active plan for suitable rehabilitation.

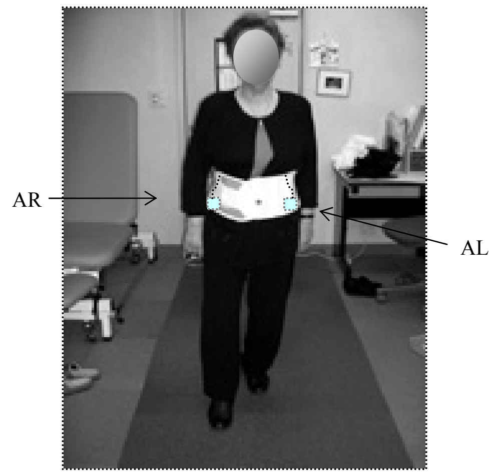

Fig. 1a. Accelerations of both hips' movement while walking in elderly subjects were measured. Two accelerometers (AR: right, AL: left) were inserted in the belt and fixed to both hips.

II. Methods

A. Portable Measurement System of Walking

Fig. 1b shows the portable measurement system of walking. This system consists of two accelerometers, controlled by a micro-PC. While walking, two accelerometers were inserted in the belt and fixed to the subject's both hips. When a switch was turned on, accelerations of both hips were recorded on a small memory card at 50Hz. A person can walk everywhere naturally using this system (see Fig. 1a). A micro PC, a memory card and batteries were held in a waist pouch, attached a wide belt.

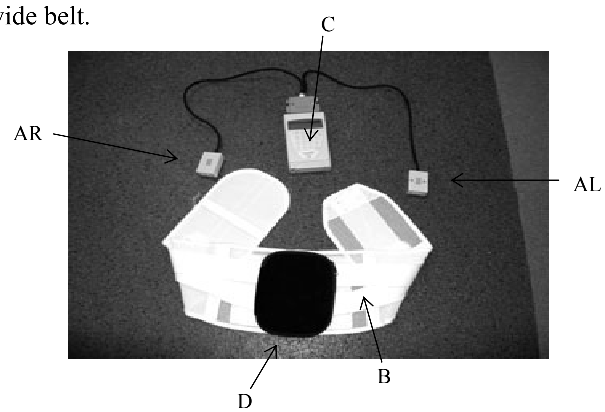

Fig. 1b. *Portable measurement system of walking*;

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AL: Accelerometer of Left, AR: Accelerometer of Right,
B: wide elastic belt,
C: box (micro-PC, memory card, batteries),
D: waist pouch.

B. Analysis of Power Spectrum using AR Modeling

Autoregressive (AR) model of order M is given by the equation (1).

$$y_n = \sum_{m=1}^{M} a_m y_{n-m} + \varepsilon_n \qquad (1)$$

where
y_n : stationary time series
a_m : AR coefficient
y_{n-m} : past observed data
ε_n : white noise

In equation (1) ε_n is a Gaussian white noise with mean zero and variance σ^2.

The estimate of the power spectral density *p(f)* of the AR model process is given by the equation (2).

$$p(f) = \frac{\sigma^2}{\left|1 - \sum_{m=1}^{M} a_m e^{-i2\pi fm}\right|^2} \qquad (2)$$

This formula defines the best prediction giving the power spectral density, which expresses the characteristics of a sequential system concisely decomposing it into periodic components [6].

III. Results and Discussion

In this study, elderly subjects (N=5 males, 65– 70 yeas old; N=20 females, 70 - 75 years old) were selected. They had slight back and knee pain. A problematic body part influences the stability of the control movement in the maintenance of standing and walking sequence. The most elderly people become lack their rhythm of walking balance, because their body alignment and standing balance become unstable. They are undergoing kinesitherapy for walking movements in rhythmic stabilization.

A. Analysis of 1/f fluctuation in walking improvement by physical exercise. (N=5 males, 65– 70 yeas old)

The fluctuations of both hips' movement while walking were measured for ten meters on a straight path. They walked at their own speed naturally with suitable shoes. Measurements were taken with subjects before and after physical exercise. Physical exercise made strong cooperation of relevant muscle movement and joints. Before physical exercise, the fluctuations of the hip, which had back and knee pain, was not rhythmic and also not proportional to 1/f fluctuation, i.e., their walking was unstable (see Fig. 2).

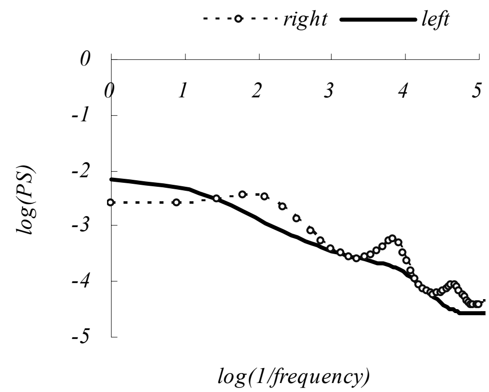

Fig. 2. Power spectra of the fluctuations of both hips' movement while walking before physical exercise. The right hip had right back and knee pain, the left hip is normal.

After one month's physical exercise, their fluctuations of both hips' movement decreased and became rhythmic while walking, and were close to proportional to 1/f fluctuation (see Fig. 3), i.e. their walking was improved, and also their pain was gone. This treatment reduced the burden on the healthy hip.

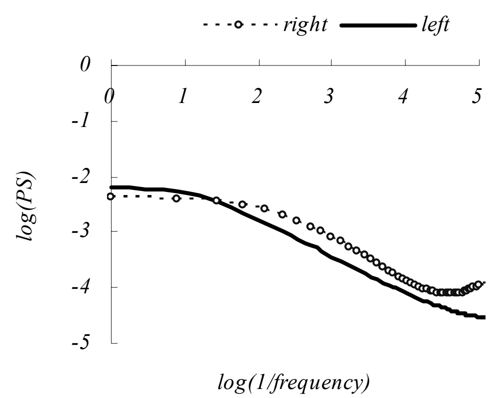

Fig. 3. Power spectra of the fluctuations of both hips' movement while walking after physical exercise.

B. Analysis of 1/f fluctuation in walking improvement using suitable shoes and shoe insoles (N=20 females, 70 - 75 years old)

One kind of medical therapy uses dynamic shoe insoles that have some pads. The shape and location of the pads on the insoles of the two feet were different. These insoles were put inside the suitable shoes. A highly experienced physical therapist (Makoto Iritani, P.T.; The Institute of Foot and Walking) visually observed the movement of the subject's body while walking. He can make suitable shoe insoles for the improvement of subjects' walking balance. The state of foot alignment, the toes, and the arch of the sole during walking are taken into consideration. The relationship between the feet and the body as a whole is considered in weight-bearing positions and movement sequence patterns, therefore this decides the position and shape of the various pads on the back of the insoles.

Shoe insoles influence the subjects to have better dynamically controlled walking balance (see Fig. 4).

Shoe insoles

Fig. 4. Making pads' shape and location on shoe insoles by walking balance.

It was observed that while walking with shoes without shoe insoles, their body alignments were not good and also each subject's feedback control movement of left and right legs was not rhythmic. The fluctuations of both hips' acceleration were different, i.e., power spectra of the fluctuations of both hips while walking were not proportional to 1/f fluctuation, showing unstable (see in Fig. 5).

After one month's physical exercise with shoes and with shoe insoles, their fluctuations of both hips' movement decreased and became rhythmic while walking. Their power spectra of the fluctuations of both hips while walking were a little closer to proportional to 1/f fluctuation (see Fig. 6).

Their walking was improved, and also their back and knee pain decreased. After two months' physical exercise with shoes and shoe insoles, their power spectra of walking balance became much closer to proportional to 1/f fluctuation.

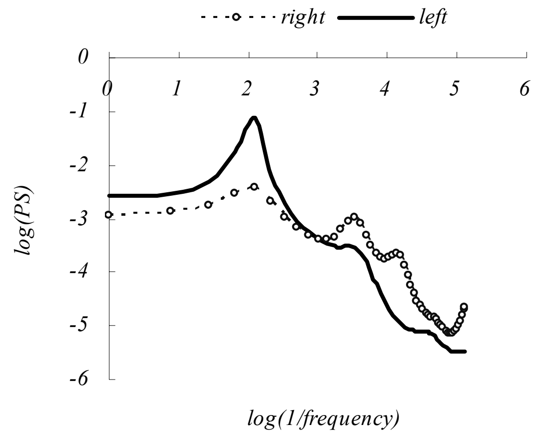

Fig. 5. Power Spectra of the fluctuations of both hips while walking with shoes without shoe insoles.

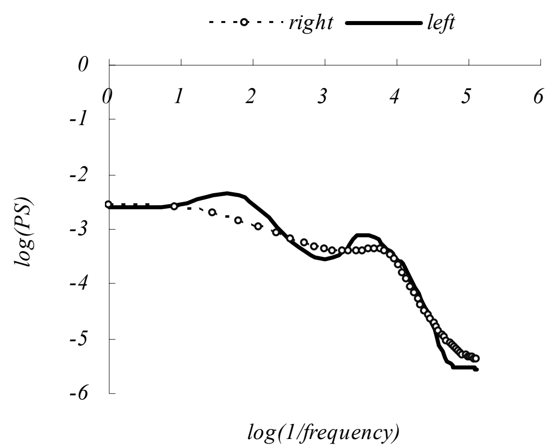

Fig. 6. Power Spectra of the fluctuations of both hips while walking with shoes and shoe insoles.

The human body has a natural system of homeostasis that maintains stable physical functions. It is well known that, when the body is stable, the power spectrum of the bio-signal is proportional to 1/f (f=frequency) fluctuations. Thus, 1/f fluctuations represent an index to stable fluctuations appearing in a normal well-balanced condition. In this study, the fluctuations of both hips' movement while walking were analyzed as bio-signals.

The condition of walking is not proportional to 1/f fluctuations, each subject got tired or had back and knee pain. The standing and walking posture of subjects became unstable. Elderly people who continue to do suitable physical exercise, walking and wearing suitable shoes, have a good balance of standing and walking.

IV. Conclusion

It is possible to improve walking balance in elderly. Most people understand the importance of walking balance after they have suffered back or leg pain. The power spectrum analysis provided clear results for the evaluation of the improvement of walking balance. If this analysis of walking balance is checked regularly, it will suggest one of evaluations of present walking stability. This study provides a potential for the understanding of medical recovery and kinesitherapy.

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