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# Spectral Analysis of Walking with Shoes and without Shoes

Masako Tsuruoka*, *Member, IEEE,* Yuriko Tsuruoka,
Ryosuke Shibasaki, *Member, IEEE,* Yoshifumi Yasuoka, *Member, IEEE*

*Abstract*— **This study analyzes the walking balance of young students based on 1/f fluctuations using Auto-Regressive (AR) modeling. There was more good walking balance than bad, influenced positively or negatively by the students' shoes. After the subjects understood their own walking condition, based on 1/f fluctuation, and had received suitable rehabilitation and shoes, their walking balance became better. This study provides a useful new method of medical evaluation in rehabilitation and physical fitness, and a means for subjects to maintain a state of well being.**

***Index Terms*—Auto-Regressive (AR) modeling, 1/f fluctuation, rehabilitation, spectral analysis, waking stability**

## I. Introduction

SINCE human bodies have an unstable biomechanical structure connected with many joints, even a single problem in the lower limbs negatively influences the control of standing posture. It also negatively influences the fluctuation of the body's center of gravity (COG), in consequence, making walking unstable. Unstable walking impairs knee or back movement and results in pain. Most people in middle and old age have osteoarthritis of the lower limbs, with associated pain. It is important to understand the characteristic of one's walking balance and to try, during the growth period, to get into good walking habits for better health.

In previous studies, normal young students who had suffered no orthopedic disorders in their lower limbs were selected to be subjects. While walking, rhythmic fluctuations of COG were observed in 20% of them and non-rhythmic fluctuations in the other 80%. Those with non-rhythmic fluctuations walked with less stability because of the negative influence of problematic posture, i.e., their abdominal or back muscles were weak, and they had a slight '*sway back*', and pelvic obliquity. After they understood how to assume a suitable posture, had exercised the relevant muscles, and begun wearing suitable shoes, their COG fluctuations were minimized and more rhythmic while walking [1]-[5].

In this study, using a portable, wearable sensor measurement system for walking, young female student subjects, aged twenty and twenty one, were measured while walking with and without shoes. Young male students wait their turn in same experimental measurement. The selected young female and male students had suffered no orthopedic disorders, such as hemiated disk, Achiles' tendon break and fracture in lower limbs. They were defined as normal subjects in this study. Spectral analysis utilizing AR modeling was done with a particular focus on the movement of the COG while walking with and without shoes.

## II. METHODS

### *A. Portable wearable sensor measurement system for walking*

Fig. 1a shows the portable system for measuring various aspects of walking. This system consists of two small, light accelerometers, controlled by a micro-PC, which can measure two parts of the body. Lithium rechargeable batteries supply electrical power to the sensors and are inserted into the subject's waist pouch. While walking, the system is worn on the subject's wrist, held in place by a wide elastic belt, with one accelerometer fixed near the subject's COG. When a switch is turned on, accelerations of the subject's COG along all three axes are recorded on a small memory card at 50Hz. A person can walk naturally anywhere using this portable measurement system (see Fig. 1b).

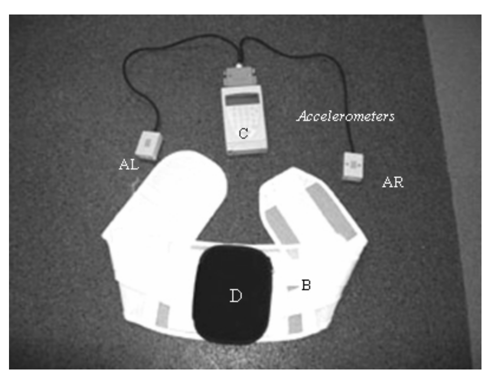


Fig. 1a. Portable system for measuring movements in walking. AR is 3-axis accelerometer Right. B is a wide elastic belt. C is a box inserted micro-PC, memory card, and batteries. D is a waist pouch.

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*M. Tsuruoka is with the Center for Spatial Information Science, University of Tokyo, Japan (corresponding author to provide phone: +81-3-5452-6415; fax: +81-3-5452-6410; e-mail: masako@iis.u-tokyo.ac.jp).

Y. Tsuruoka is with the Institute of Statistical Mathematics, Tokyo, Japan (e-mail: tsuruoka@ism.ac.jp).

R. Shibasaki is with the Center for Spatial Information Science, University of Tokyo, Japan (e-mail: shiba@csis.u-tokyo.ac.jp).

Y. Yasuoka is with the Institute of Industrial Science, University of Tokyo, Japan (e-mail: yyasuoka@iis.u-tokyo.ac.jp).

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Fig. 1b. The COG of young subject was measured by a portable measurement system using accelerometer while walking.

### *B. Analysis of Power Spectrum using AR Modeling*

Multivariate AR modeling is given by the equation (1).

Nor

$$x_i(s)=\sum_{j=1}^{K}\sum_{m=1}^{M}a_{ij}(m)x_j(s-m)+u_i(s) \qquad (1)$$

where
$x_i(s)$ = stationary time series;
$x_j(s\text{-}m)$ = past observed data;
$u_i(s)$ = white noise;
$a_{ij}(m)$ = AR coefficient.

The frequency response function $a_{ij}(f)$ of $x_i(s)$ to the input $x_j(s)$ is given by the equation (2).

$$a_{ij}(f)=\sum_{m=1}^{M}a_{ij}(m)e^{-i2\pi fm} \qquad (2)$$

where
$e^{-i2\pi fm}$ = Fourier transform of frequency response.

The system given by (1) is a feedback system within which $x_j(s)$ is connected to $x_i(s)$ by an element having the frequency response function $a_{ij}(f)$ and each $x_i(s)$ has its own noise source $u_j(s)$'s.

Thus, $x_i(s)$ can be expressed as a sum of the influences of $u_j(s)$'s. The estimate of the power spectral density $p(f)$ is given by the equation (3).

$$p(f)=\frac{\sigma^2(M)}{\left|1-\sum_{m=1}^{M}a(m)e^{-i2\pi fm}\right|^2} \qquad (3)$$

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

### *Spectral Analysis of Walking Balance by Normal Subjects*

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 represents an index of stable fluctuations appearing in a normal well-balanced condition. In this study, the fluctuation of COG while walking was analyzed as a bio-signal.

Normal Subjects: N=50 females, 20-21 years old

Normal young female students, who had suffered no orthopedic lower-limb disorders, were selected to be subjects. Their acceleration of COG was measured while walking with and without their regularly worn shoes.

The following four characteristic groups were identified, based on 1/f fluctuations, as shown in Fig. 2. There are four characteristic, Case A, Case B, Case C, Case D patterns of walking balance with and without shoes. In daily movement, students walk wearing shoes and carrying a bag, therefore their walking balance is mechanically influenced by these items.

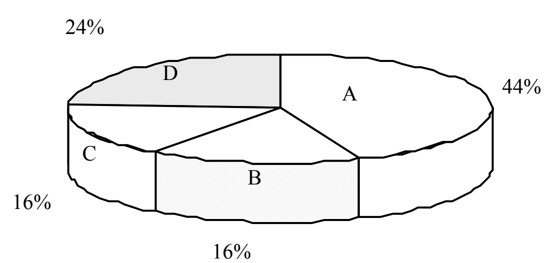


Fig. 2. Four characteristic patterns of walking balance with and without shoes.

It is important to know that their walking balance has suffered a positive or negative influence from using these items. In this study, their walking balance was measured with shoes and without shoes. When they have suffered a negative influence from their regularly worn shoes, it is better to change them as soon as possible.

*Case A (44%): positive walking with and without shoes*

The power spectra of COG of students walking both with and without shoes were proportional to 1/f fluctuation, i.e., their walking was stable, as shown in Fig. 3a. (the sagittal plane) and Fig. 3b. (the frontal plane). Their posture and walking were good and healthy, and their shoes positively supported their walking.

*Case B (16%): positive walking with shoes*

The power spectra of the COG of students walking without shoes were not proportional to 1/f fluctuations, indicating unstable walking. The power spectra of the COG for walking with shoes, on the other hand, indicated good walking, as shown in Fig. 4a (sagittal plane) and Fig. 4b (frontal plane).

Their shoes appeared to support their walking positively. Their shoe selection was good.

*Case C (16%): positive walking without shoes but negative walking with shoes*

The power spectra of the COG of students walking without shoes were proportional to 1/f fluctuations, indicating stable walking, but the power spectra of walking with shoes was not proportional to 1/f fluctuations, suggesting an unstable walking, as shown in Fig. 5a (sagittal plane) and Fig. 5b (frontal plane). It appears that their shoes influenced their walking negatively. Unsuitable shoes disturb stable walking, and it appears that their shoes did not support their walking, which needs improvement. After changing to comfortable shoes, the COG power spectra of walking were proportional to 1/f fluctuations. While their walking was stable, their back pain was gone.

*Case D (16%): walking needing improvement, both with and without shoes*

The COG power spectra of students walking were not proportional to 1/f fluctuations, neither with nor without shoes, indicating the unstable walking shown in Fig. 6a (sagittal plane) and Fig. 6b (frontal plane).

The walking of these subjects needs suitable rehabilitation and shoes. If they do not improve their walking, they will eventually suffer orthopedic problems.

After they understood how to assume a suitable posture, exercise the relevant muscles, wear suitable shoes and carry a bag alternately on their right and left shoulder, their COG power spectra became better and were nearly proportional to 1/f fluctuations, indicating stable walking.

## IV CONCLUSION

This study clearly shows characteristics of walking balance for individual subjects, both with and without shoes. It is said that even young subjects did not have suitable walking balance. The spectral analysis provides clear results for evaluation of improvement of walking balance. To get suitable walking balance, each subject has to understand her own walking condition, using the perspective of 1/f fluctuations, and needs suitable rehabilitation. This study is beneficial since it provides a useful method of medical evaluation in rehabilitation and physical fitness, and a means for subjects to maintain a state of well being.

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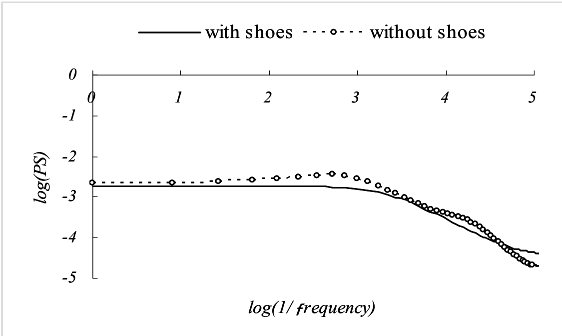


Fig. 3a. (sagittal plane) Walking was positive both with and without shoes

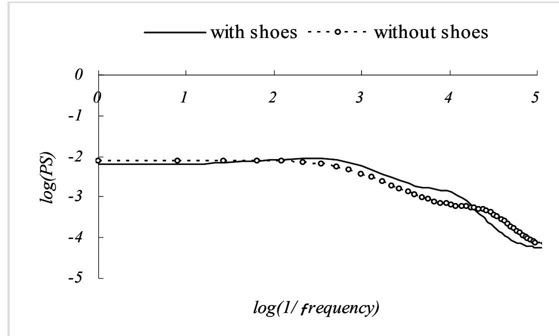


Fig. 3b. (frontal plane) Walking was positive both with and without shoes

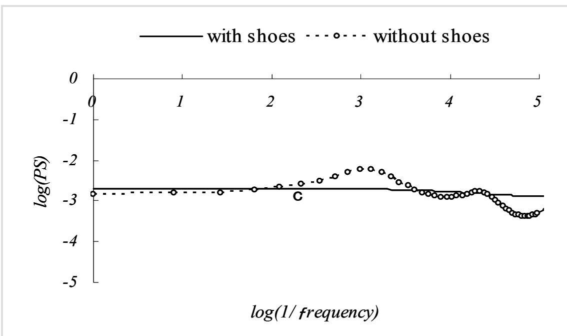


Fig. 4a. (sagittal plane) Positive influence of walking with shoes

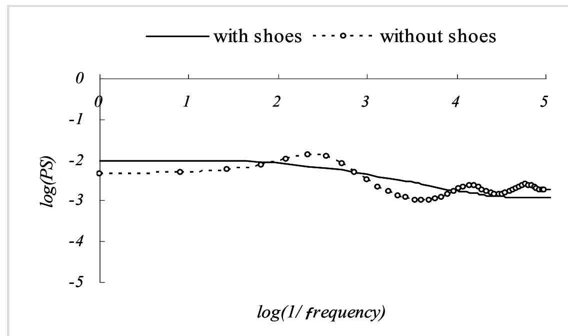


Fig. 4b. (frontal plane) Positive influence of walking with shoes

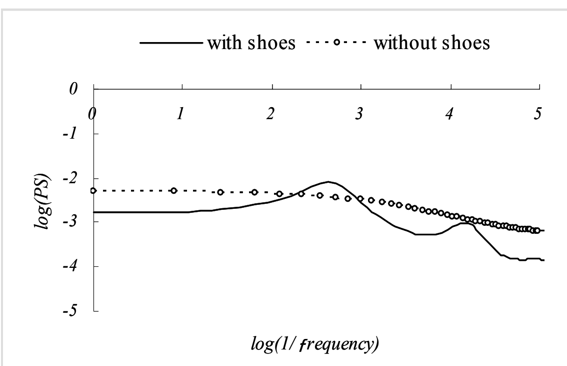


Fig. 5a. (sagittal plane) Positive influence of walking without shoes and negative influence of walking with shoes.

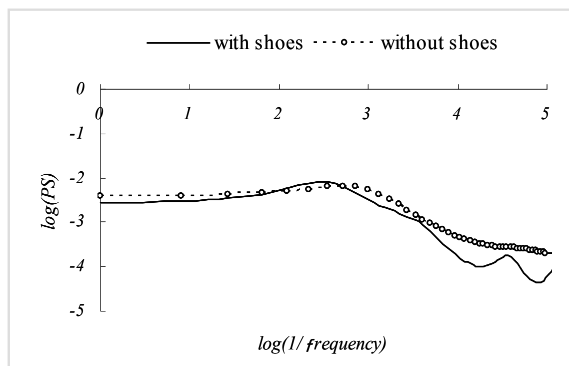


Fig. 5b. (frontal plane) Positive influence of walking without shoes, negative influence of walking with shoes.

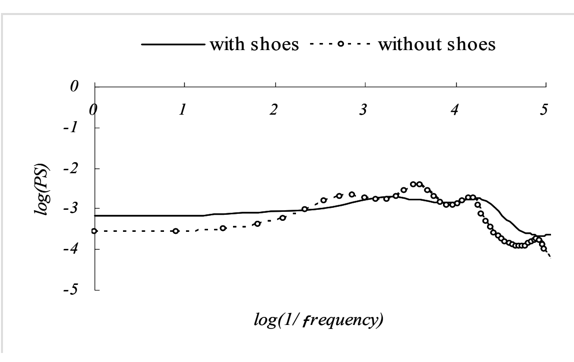


Fig. 6a. (sagittal plane) Walking needs improvement, both with and without shoes.

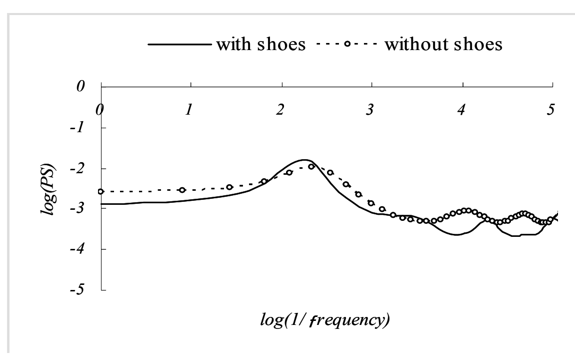


Fig. 6b. (frontal plane) Walking needs improvement, both with and without shoes.