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Analysis of Factors Affecting Improvement of Walking Stability

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Abstract**—Walking balance becomes less stable under the influence of a problematic posture or back. This problem was analyzed on the basis of two new approaches. The first approach is a useful walking analyzer system. It is a small, wearable, micro PC-assisted portable measurement system, consisting of two accelerometers that acquire time series data of the left and right hips' movements while walking.**

However, it was difficult to analyze directly the characteristics of movement stability using the raw measurement data. The second approach was an analysis of impulse response using Auto Regressive (AR) modeling. Once a subject was aware of the correct posture, the fluctuation of both sides of the subject's hip while walking was improved to be more rhythmic in the female students. The analysis of impulse response, utilizing AR modeling, provided clear results for the evaluation of improvement to walking stability.

The impulse response of movement factors enables analysis of their dynamical relations. The biofeedback control analysis of the left and right sides of the subjects' hip while walking using this analyzer system suggests a new potential for the understanding of walking stability in rehabilitation and also physical fitness in daily movement. After the subjects had received suitable rehabilitation, their walking stability improved satisfactorily. This study provides a useful method of medical evaluation in rehabilitation and physical fitness, and a means for subjects to maintain a state of well being.

Keywords—AR modeling, impulse response, walking stability, rehabilitation

I. INTRODUCTION

Human bodies have an unstable biomechanical structure connected with many joints, one 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 back movement and results in pain. Most people in middle and older 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.

The fluctuation of movement, i.e., the feedback control movement of left and right hips in the walking sequence becomes less stable under the influence of a problematic part of the lower limb or back. It also negatively influences the fluctuation of the COG, in consequence, making walking unstable. Unstable walking impairs back movement and results in pain. Most people in middle and older 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 [1]-[6].

AR modeling defines the best prediction, giving the power spectral density, which expresses the characteristics of a sequential system concisely, decomposing it into periodic components [7]-[8].

In this study, using a wearable sensor measurement system for walking, various kinds of walking were measured while walking with a bag or without a bag, before or after medical therapy, and before or after physical exercise in young students.

II. METHODS

A. *Portable wearable sensor measurement system for walking*

The portable system we have designed measures 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, or right and left accelerometers fixed the subject's right and left sides of the hip. When a switch is turned on, the serial accelerations in three axes of subject's COG or both sides of the hip are recorded simultaneously on a small memory card at 50 Hz.

A subject can walk naturally anywhere using this portable measurement system (see Fig. 1.)

Fig. 1 The left and right hips of the subject were measured by a potable measurement system using accelerometers while walking with a bag. A is the accelerometer inside the belt, B is a waist pouch inserted with a micro-PC, memory card, and batteries.

B. Analysis of power spectrum using AR modeling

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

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

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.

AR modeling was done with a particular focus on the feedback control movement: the movement of left and right sides of hip in walking balance.

C. Analysis of Impulse response on walking stability

The homeostasis is maintained in the human body. While walking, the movement of the left hip controls that of right hip, and vice versa. This is a feedback control loop of two variables (see Fig. 2.).

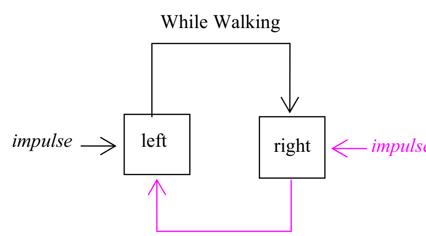

Fig. 2 Feedback control loop of left and right side of the hip movement.

The computational impulse of two times the standard deviation (S.D.) of fluctuation of each subject's hip movement was applied as white noise in this study. When the impulse is given to left hip movement, it is transmitted and its response appears on the right hip movement, and vice versa [7]-[8].

III. RESULTS AND DISCUSSION

A. Impulse response analysis of walking improvement

(1) Kinesitherapy with dynamic shoe insoles

Subjects: N=5, aged 60-70 female

Subjects walked everyday with back pain. The condition of their posture and walking balance were increasingly unstable. They were undergoing kinesitherapy with dynamic shoe insoles that have some small pads. The shape and location of pads on the insoles of the two feet are different.

These insoles are put inside the shoes in order to help subjects to improve walking balance dynamically (see Fig. 3).

This kinesitherapy has achieved the effect with a good rehabilitation. It was observed that before therapy with dynamic shoe insoles, their body alignments were not well and also each person's feedback control movement of left and right hips was not rhythmic while walking. After taking off the dynamic shoe insoles, the subjects' walking balance has continued to improve.

In hospital, highly experienced doctors and physical therapists are used to observing the movement of the patient visually, and their observation are not digital, so they cannot compare enough different movements, or the degree of improvement of movements.

Before kinesitherapy of walking with dynamic shoe insoles, the fluctuations of both hips' acceleration were different and were seemingly unstable. The value and the duration of the impulse response of the right hip were larger than that of the left one (see Fig. 4).

It is said that the left side carries the right side's burden.After a month of kinesitherapy with dynamic insoles, the fluctuations of both hips became more rhythmic and similar to each other. Both values and duration of the impulse responses of the right and left hip became smaller and more similar to each other (see Fig. 5).

It is said that the right side of hip's burden disappeared. It is important to reduce both sides burden and back pain.

shoe insoles

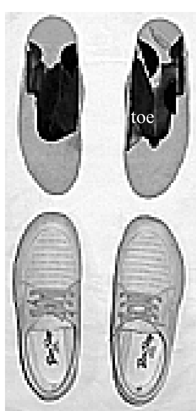

Fig. 3 Kinesitherapy of walking with dynamic shoe insoles

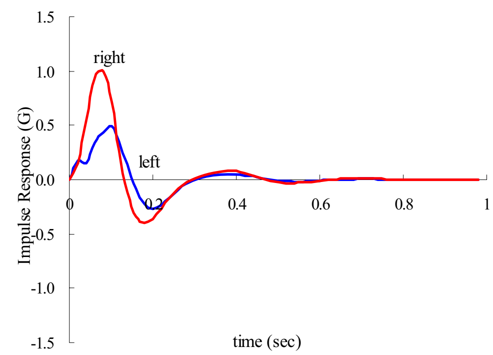

Fig. 4 Impulse Response of both hips while walking before kinesitherapy with dynamic shoe insoles.

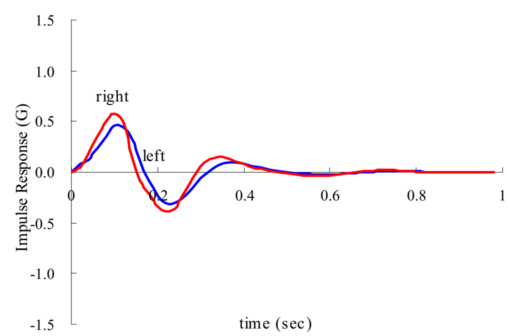

Fig. 5 Impulse Response of both hips while walking after kinesitherapy with dynamic shoe insoles.

(2) Kinesitherapy with exercises to strengthen abdominal muscles and the back

Subjects: N=25, aged 20-21 female

With physically unimpaired subjects without a history of orthopedics disease, 25 female students from 20 to 21 years old, were selected. The acceleration of the movement of the right and left hips was measured while walking with and without a heavy bag (bag weight = 3 kg).

In the case of walking without a bag:

It is said that

(1) 48 % of them had no trouble walking, good walking balance.

(2) 40 % of them had larger impulse response in the right hip than the left one.

(3) 12 % of them had larger impulse response in the left hip than right one (see Fig. 6).

It was observed that the impulse responses were imbalanced in over half of the subjects.

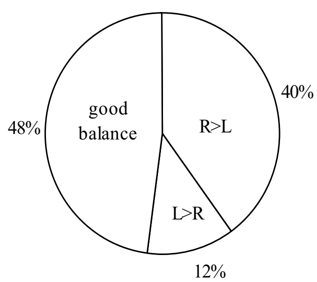

Fig. 6 Impulse response of walking without a bag

In the case of walking with a bag:

It is said that

(1) 36% of subjects had good posture and no trouble walking, good walking balance.

(2) 44% of subjects had larger impulse response in the right hip than the left one.

(3) 20% of subjects had larger impulse response in the left hip than right one (see Fig. 7).

It was observed that over half of them had not good balance while walking with a bag. In the case of students who had good posture, the value and the duration of the impulse response of both hips were similar, while walking without a bag (see Fig. 8), and with a bag (see Fig. 9).

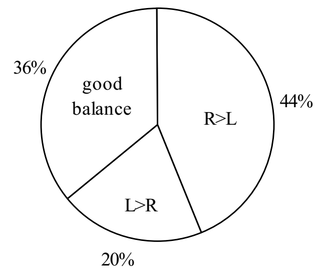

Fig. 7 Impulse response of walking with a bag

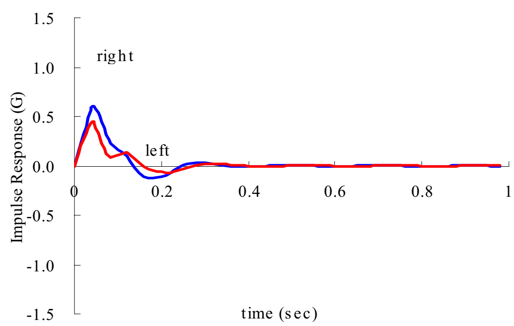

Fig. 8 Impulse response of both hips while good balance walking without a bag by students who have good posture.

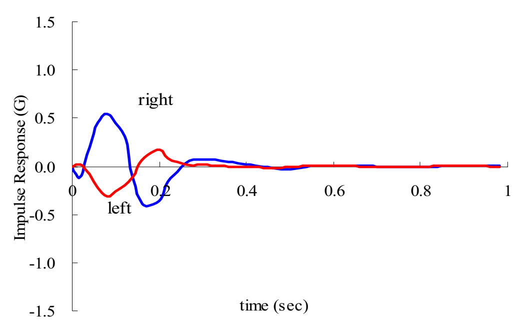

Fig. 9 Impulse response of both hips while good balance walking with a bag by students who have good posture.

It is said that students who had excellent posture did not influenced in walking balance with a bag (bag weight: 3kg).

In the case of students who had bad posture, the value and the duration of the impulse response of both hips were not similar. Those of the impulse response of right or left hip were larger while walking without a bag (see Fig. 10) and with a bag (see Fig.11).

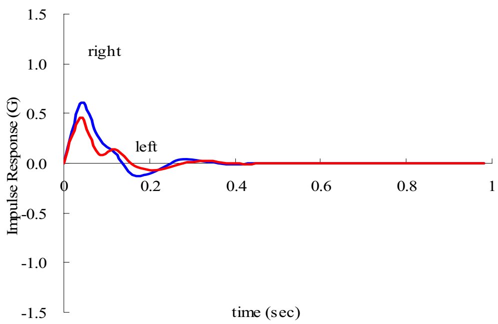

Fig. 10 Impulse response of both hips while bad balance walking without a bag by students who have bad posture.

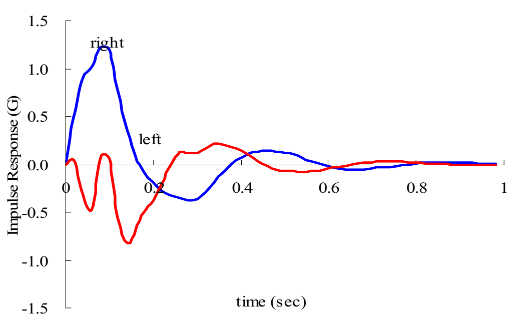

Fig. 11 Impulse response of both hips while bad balance walking with a bag before kinesitherapy of exercises by students who have bad posture.

After a month of kinesitherapy of exercises to strengthen abdominal muscles and the back, both values and duration of the impulse responses of the right and left hip became smaller and more similar to each other (see Fig. 12).

In the younger students, the negative influence of walking with a heavy bag was smaller than those of the older subjects. Subjects in the middle and old age, the negative influence of walking with a heavy bag became be larger, with associated pain.

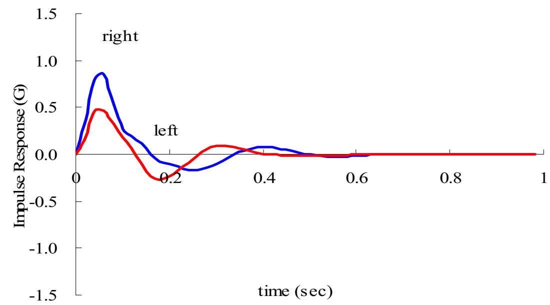

Fig. 12 Impulse response of both hips while walking with a bag after kinesitherapy of exercises by students who have bad posture.

In the case of walking with a backpack, the weight distribution was balanced. Their impulse response of both hips became be smaller and more similar to each other in the younger subjects and especially older subjects (see Fig. 13).

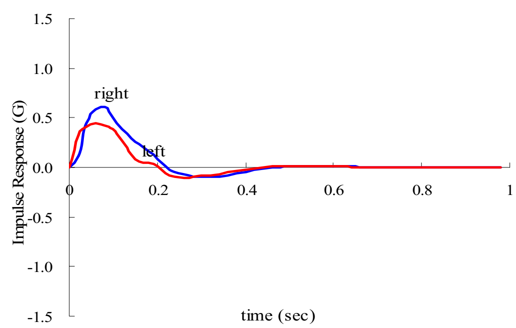

Fig. 13 Impulse response of both hips while bad balance walking with a backpack.

The degree of difference of each hip's response also indicated the degree of unstable walking. The value and duration to the impulse response curves showed which hip is stronger and to what degree. In the case of the right hip was strong against the impulse, and the response value of left hip was small, because the impulse was absorbed and wasn't transmitted to the left hip, and visa versa. In this case, the left hip was strong against the impulse. After the subjects understood their own walking condition, and they had received suitable medical therapy, their walking stability improved satisfactorily.

IV CONCLUSION

The spectral analysis of *1/f* fluctuation and impulse response of walking balance utilizing AR modeling provided clear results for the evaluation of improvement to walking stability.

This study provides a useful method of medical evaluation in rehabilitation and physical fitness, and a means for subjects to maintain a state of well being. To achieve suitable walking balance, each subject has to understand the mechanical balance and rhythm of their own walking, using these methods, and needs suitable shoes and therapies.

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