DEVELOPMENT OF GAIT EVALUATION SYSTEM FOR HEALTHCARE SERVICE

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SUMMARY
In order to evaluate intraindividual changes of gait pattern of healthy people by intervention or training, we developed a method that can reconstruct the patterns of each joint angle and moment of lower extremity without motion capture system. First, we measured gait motion of 19 health subjects, and constructed biomechanical gait database statistically. This database was composed of 8 principal component (PC) scores. We defined the PC scores as gait evaluation (GE) scores. The GE scores were related to parameterized ground reaction forces during walking and gait information like gait velocity using multiple regression analysis. Therefore, this method is easy to apply to a treadmill with force sensors in the field of healthcare industry. We measured the change of gait pattern under the coaching by a gait trainer using this method. As a result, the differences of the GE scores by the training were larger than the intraindividual deviations. This result shows that our method can evaluate intraindividual changes of gait pattern by intervention.

INTRODUCTION
Healthcare service industry in Japan focuses attention on various effects of gait. In the case of many fitness clubs and gyms, there are several treadmills for keeping their users healthy. These treadmills can measure some basic gait information of the users like gait speed or gait cycle. But these cannot examine biomechanical information like joint moment. But it is difficult to install a motion capture system, which is expensive and needs broad area. Furthermore, it is necessary not only to clarify the intraindividual changes of the users by intervention or training, but also to visualize the gait pattern for the correct understanding for the users.

Raptopoulos et al. [1] and Wu et al. [2] proposed to classify each joint angle of lower extremity of healthy people during walking using principal component analysis (PCA). The principal component (PC) scores show the interindividual differences of kinematic pattern of gait and can reconstruct gait patterns. These methods are expected to be adaptable for the healthcare service industry. However, these methods cannot reconstruct the kinetic condition, which is important to evaluate the muscular loads and the activities of muscles around each joint during walking biomechanically.

We develop a gait evaluation method, which is adaptable for a treadmill and force sensors without Mocap system. It is easier to attach force sensors under the treadmill than to install motion capture system in fitness clubs or gyms. This method includes kinematic and kinetic gait pattern database using PCA. These data are measured originally in the laboratory using motion capture system and force plates. These PC scores relate to the ground reaction forces during walking and some gait information like gait velocity. When these data measured, the PC scores are estimated. These PC scores can reconstruct and evaluate biomechanical gait conditions of lower extremity.

METHODS
Gait patterns of 19 adult male subjects (27.7±6.7 year-old, height 1.73±0.05 m, and weight 67.7±17.3 kg) were measured in the laboratory. They were instructed to walk on the lane as usual. There were force plates (BP400600-10000PT, AMTI) in the middle of the lane and the ground reaction forces were measured during walking. The displacements of positions of each joint of the lower extremity were also measured using Mocap system (Vicon Nexus, Vicon) simultaneously.

From the measurement, the set of joint angle and moment was calculated, which was projected on a parallel plane to the sagittal plane. These data were composed of 6 time series data; the joint flexion/extension angle patterns and the joint flexion/extension moment patterns of hip, knee, and ankle. The joint moments were normalized by the product of height and weight of each subject. These time series data during one cycle were clipped from the timing of the right heel contact to the timing of the same right heel contact again. Furthermore, each time series was normalized by the gait cycle time and was divided into 101 variables every 1 %.

A set of the data was discretized into 101×6 variables per one subject. The 606 variables are not independent with each other. Therefore, we tried to compress the information carried by the data using PCA. These PC scores were named gait evaluation (GE) scores.

We also parameterized anterior-posterior and vertical ground reaction forces using PCA, respectively. The relationship between the GE scores and the parameterized ground reaction forces were analyzed using stepwise multiple regression analysis.

RESULTS AND DISCUSSION
The cumulative contribution rate of the first 8 GE scores was 86.2 %. Figure 1 shows relationships between the first 3 GE scores (cum. contribution rate = 50.6 %) and the original 606 variables. The horizontal axis means the variables of each joint angle or moment during gait cycle. And the vertical axis means the factor loadings for each GE score. If the absolute value of the factor loading is large, the variable has a high
correlation with the GE score. As a result, GE1 is interpreted as mainly knee motion during stance phase and hip motion from late swing phase to early stance phase. This means how to absorb the impact at heel contact. GE2 is interpreted as mainly hip motion from middle stance phase to swing phase and knee and ankle motion during swing phase. This means the magnitude of extension of hip at toe off. Reversely, GE3 is interpreted as hip motion during early stance phase. This means the magnitude of hip flexion at heel contact.

Figure 1: A relationship between the first 3 GE scores and the original 606 variables.

When the ground forces are measured, the ground forces are parameterized, and then the first 8 GE scores are estimated from formulae of the parameterized force data.

We measured another one male subject (31 year-old, 1.76 m, 57.0 kg) in order to validate the accuracy of the method. Figure 2 shows the estimated result. As a result, the maximum error of joint angle was 10.8° in ankle and the average error was 2.85°. The maximum error of joint normalized moment was 1.30 in knee and the average error was 0.33. Especially, the reason why the errors increased during swing phase was considered that the estimations were depended on the ground reaction forces only, which were less affected by the motion during swing phase. However the estimated result agreed well with the measured result except during swing phase.

In order to evaluate intraindividual changes of gait pattern, we measured the change of gait pattern under the coaching by a gait trainer. A male subject (36 year-old, 1.66 m, 65.0 kg) was coached for his own walking by a gait trainer, and his walking was measure three times: before training, after training, and 3 weeks after training. Figure 3 shows the result. The horizontal axis and vertical axis of the map mean GE1 and GE2, respectively. First, he walked with narrow hip extension. After the training, his hip extension became wider, but his knee flexion became larger, too. Three weeks after training, his knee flexion became smaller keeping his hip extension widely. The differences of the GE scores by the training were larger than the intraindividual deviations clearly. This result shows that our method can evaluate intraindividual changes of gait pattern by intervention.

CONCLUSIONS
We developed a new gait evaluation method. The gait pattern of a user can be estimated from ground reaction force data and gait information without Mocap system. Besides, the method can evaluate intraindividual changes of gait pattern by intervention. In our future work, we will apply this method to a treadmill with force sensors.

REFERENCES