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Abstract:　[Purpose] This study investigated the reliability of triaxial accelerometric gait analysis. [Subjects] The study subjects were 22healthy individuals (average age of 20.3±0.5years). [Methods] Acceleration was measured during walking at a comfortable speed, by using a triaxial accelerometer with a belt at the level of the subject's lower back. Acceleration at initial contact during the stance phase was analyzed for each direction (vertical, anterior-posterior and mediolateral).
Reliability was determined using models of intraclass correlation coefficients (ICC's).
[Results] By the test-retest method, the average of intraclass correlation coefficients, the ICC's were generally high, especially on Mediolateral (ML) acceleration Lability, Antero-posterior (AP) acceleration Regularity.
[Conclusion] We conclude that the method is reliable and has definite potential for clinical gait analysis.

Key words: triaxial accelerometry, reliability, gait analysis

Introduction

In analyzing gait, stabilometers, force plates and three-dimensional motion analyses have been used.

However, in previous reports (Yamada 2006;Ihira 2011), root mean square (RMS) and auto correlation (AC) computed from the acceleration signal during walking were used as an index of walking pattern.

Accelerometers are available at low cost, and accelerometry has been used for various biomechanical purposes (Winter1990). The use of trunk acceleration measurements has been identified as a possible measure of balance during walking (Yack and Berger1993), and in 2002 reference data were presented for different gait parameters in normal subjects (Auvient2002). The equipment is easy to use and does not require fixed frames of reference. However methodological problems may be one reason for the limited use of accelerometers in gait analysis, and these must be solved in order to test the validity and reliability of the method.

The purpose of this study was to evaluate the test-retest reliability of triaxial accelerometric gait analysis.

Subjects and Methods

The study participants were 22 students enrolled at N university in Saga Prefecture in 2012. All the participants signed informed consent forms. Table1 breaks down the participants by sex and age.

Table 1. General characteristics of the subjects (n=22)

	Mean±SD	Max～Min
Age（year）	20.3±0.5	22～30
Height（㎝）	163.5±8.1	178～148
Weight（㎏）	57.5±11.7	83～41
BMI	21.1±3.0	26.1～18.7

Linear accelerations in a±60m/sec^{2}range were measured using a lightweight (60g) triaxial accelerometer (MicroStone Ltd., Japan) (Fig.1). The accelerometer was attached to an elastic belt worn by the sub-

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jects such that the three axes were aligned close to the anatomical axes (antero-posterior [AP], mediolateral [ML] and vertical [V]). Special care was taken to place the instrument centrally on the lumbar spine at the level of the third lumbar vertebra where the opposing rotations of the thorax and pelvis most efficiently cancel each other (Moe-Nilssen1998) (Fig.2). Acceleration was sampled at100Hz. After testing, the data logger was connected to a PC and the raw data were downloaded into a database for later off-line analysis.

A10-m walking distance on a flat floor with no obstacles was arranged in an indoor university environment. All subjects wore their usual walking shoes, avoiding high heels or hard-soled shoes.

A period of steady-state walking was selected from the recording of each subject. Particular points in the gait cycle were identified on the vertical acceleration curve in a preliminary study (unpublished data) (Fig.3).

Acceleration at initial contact during the stance phase was analyzed for each direction (vertical, anterior-posterior and mediolateral).

The acceleration was analyzed by using MATLAB software (The Math Works Inc.) for calculating Root Mean Square (RMS) values and Auto Correlation (AC) values of the acceleration signal, which were used as a gait lability index and a gait regularity index, respectively.

RMS and AC was calculated from the following formulas.

$\mathrm{RMS} = \int_0^{\pi} \sin(x)\, d_x$, Z=trapz (t, a).

The integration of a is computed as t.

Acceleration: a; time: t

$\mathrm{AC} = 1/\mathrm{n} \sum_{1-0}^{n-1} x(k)\, y(t+k)$, R=corrcoef (t, a)

xt: a-ave/SD; process hold-up time: k

Fig. 1 Accelerations in a $\pm 60 \mathrm{m/sec}^2$ range were measured using a lightweight (60g) tri-axial accelerometer (MicroStone Ltd., Japan)

Fig. 2 The accelerometers lie over the middle of the lower back in a semi-elastic belt fastened around the subject's waist.

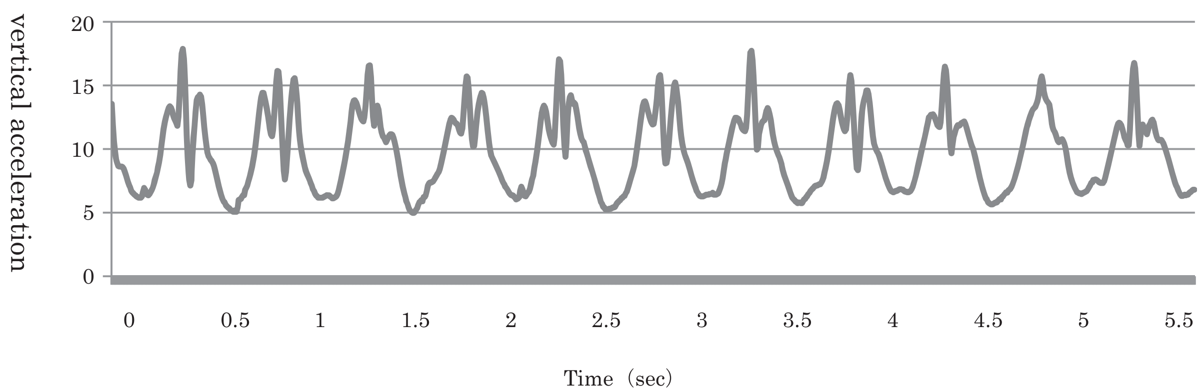

Fig. 3 Particular points in the gait cycle were identified on a vertical acceleration curve in a preliminary study.

In this study, a test-retest design was chosen in order to evaluate the stability of measurement. Statistical analyses were performed using SPSS18.

Results

In general, high average values of intraclass correlation coefficients (ICC's) were obtained by the test-retest method, and the average values were particularly high regarding Mediolateral (ML) acceleration lability and Antero-posterior (AP) acceleration regularity (Table 2).

Table 2. Relative Reliability of Acceleration Parameters (n=22)

	Mean±SD	ICC (1, 1)
Lability		
AP acceleration (m/s^2)	−0.09±0.92	0.36*
V acceleration (m/s^2)	5.08±1.87	0.79**
ML acceleration (m/s^2)	0.47±0.51	0.86**
Regularity		
AP acceleration (m/s^2)	0.59±1.44	0.98**
V acceleration (m/s^2)	0.33±0.14	0.74**
ML acceleration (m/s^2)	0.33±0.24	0.31

*p<0.05, **p<0.01
Abbreviations: AP, antero-posterior; ML, mediolateral; V, vertical

Discussion

This study found the reliability of trunk acclerometric gait analysis to be satisfactory, with high values for interclass correlation coefficients (ICCs). The gait analysis method presented allows trunk accelerations to be measured at walking speed, and suggests that it is possible to estimate acceleration lability and regularity at standardized walking speeds. This makes the method highly applicable in clinical settings.

As criteria for clinical acceptability, Fleiss suggested that ICC<0.4 demonstrates poor reliability, 0.4> ICC<0.75 fair to good reliability, and ICC>0.75 excellent reliability (Fleiss1986). Using this notion of estimation, the ICC values we obtained were excellent, especially in Lability acceleration.

The ICC of Lability acceleration was 0.36 for AP, 0.79 for V and 0.86 for ML, as a result of the reproducibility examination of this research. The ICC of Regularity acceleration was 0.98 for AP, 0.74 for V and 0.31 for ML.

Particularly high reproducibility was obtained in connection with ML lability acceleration and AP regularity acceleration.

We conclude that the method is reliable and has definite potential for clinical gait analysis.

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