Evaluation of Gait Characteristics in Subjects With Locomotive Syndrome Using the Wearable Gait Sensors

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Research Article

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Abstract

Background: Locomotive syndrome (LS) is a condition where a person requires nursing care services due to problems with locomotive abilities and musculoskeletal systems. Individuals with LS have a reduced walking speed compared to those without LS. However, differences in lower-limb kinematics and during walking between individuals with and without LS are not fully understood. The purpose of this study is to clarify the characteristics of gait kinematics using wearable sensors for individuals with LS.

Methods: We assessed 125 people aged 65 years and older who utilized a public health promotion facility. The participants were grouped into Non-LS, LS-stage 1, LS-stage 2 (large number indicate worse locomotive ability) based on 25-question Geriatric Locomotive Function Scale (GLFS-25). Spatiotemporal parameters and lower-limb kinematics during 10-m walking test were analyzed by 7-inertia-sensors based motion analysis system. Peak joint angles during stance and swing phase as well as gait speed, cadence and step length were compared among all groups.

Results: The number of each LS stage was 69, 33, 23 for Non-LS, LS-stage 1, LS-stage 2, respectively. LS-stage2 group showed significantly smaller peak hip extension angle, hip flexion angle and knee flexion angle than Non-LS group (hip extension: Non-LS: 9.5 ± 5.3°, LS-stage 2: 4.2 ± 8.2°, $P = 0.002$; hip flexion: No-LS: 34.2 ± 8.8°, LS-stage 2: 28.5 ± 9.5°, $P = 0.026$; knee flexion: Non-LS: 65.2 ± 18.7°, LS-stage 2: 50.6 ± 18.5°, $P = 0.005$). LS-stage 1 and LS-stage 2 groups showed significantly slower gait speed than Non-LS group (Non-LS 1.3 ± 0.2 m/s, LS-stage1 1.2 ± 0.2 m/s, LS-stage2 1.1 ± 0.2 m/s, $P < 0.001$).

Conclusions: LS-stage2 group showed significantly different lower-limb kinematics compared with Non-LS group including smaller hip extension, hip flexion and knee flexion. The intervention based on these kinematic characteristics measured by wearable sensors would be useful to improve the locomotive ability for individuals classified LS-stage2.

Background

Aging of the society is rapidly progressing along with the number of musculoskeletal related disease cases in Japan [1]. Musculoskeletal disorders account for 20% of the causes for elderly needing nursing care services in Japan [2]. In this context, the Japanese Orthopaedic Association (JOA) proposed ‘locomotive syndrome (LS)’ to recognize musculoskeletal dysfunctions earlier and prevent the progression of those disabilities at an early stage [2]. LS is referred as a condition coming to require nursing care or having risks of developing such a condition because of problems of the locomotive disabilities and musculoskeletal systems [2, 3]. The prevalence of LS between 40-79s was reported 10.2-11.9% and the number of LS is estimated 6.5-7.5 million in Japan [4, 5].

LS is diagnosed by 25-question Geriatric Locomotive Function Scale (GLFS-25) [6]. GLFS-25 is developed as a screening tool for the early detection of LS, which is a self-administration questionnaire that consists of four questions on pain, 16 questions on activities of daily living, three questions on activities of social living, and two questions on mental health status, covering various aspects of the patient's last month [6].

Higher scores of GLFS-25 indicates lower locomotive functions [6], and those with higher GLFS-25 point walked with slower speeds [7]. Mastumoto et al. also reported that gait speed with LS was slow and one of the gait parameters associated with LS [8]. However, there have been no reports on gait kinematics in the subjects of LS and the relationship between severity of LS stage and gait kinematics and parameters is also unclear. This is because conventional motion analysis using an optical method is a laboratory-based measurement and requires considerable amount of time to analyze.

Recently, we have developed a wearable sensor-based 3D motion analysis system called "H-Gait system" [9]. This system can analyze the motion characteristics of lower limbs without optical tracking by using seven wearable sensors consisting of three-axis outside the laboratory in a short time [10]. Although the previous study suggested the application to the knee osteoarthritis (OA) patients [11] and that to the hip OA patients [12], this system could apply to the subjects of LS in community-dwelling elderly. Understanding the difference in gait kinematics and parameters between individuals with and without LS is informative for the prevention of LS severity. The purpose of this study was to investigate the gait characteristics of LS including gait kinematics and spatiotemporal gait parameters using a wearable sensor system.

Methods

Participants

Participants were recruited from local residents who utilized a public health promotion facility at Iwamizawa city, Japan. A total of 125 individuals participated in the present study (20 male and 105 female participants; 73.0 ± 6.7 years old). The inclusion criteria was age equal to or older than 65 years old. Individuals were excluded from this study if they reported difficulty in walking without aids. The participants signed informed consent forms before their participation. This study was approved by the review board of our Institution (18-50).

Assessment of Locomotive Syndrome

Participants were grouped into the following three groups based on results of GLFS-25 and performed a 10-meter walk test (Fig. 1). Each item of GLFS-25 is graded with 5-point [6]. A total score ranges from 0 (no impairment) to 100 (severe impairment) and is used for stage division according to the following criteria: stage 0 (Non-LS) is 0–6 points, LS-stage 1 is 7–15 points, LS-stage 2 is 16–100points [13]. Reliability and validity of GLFS-25 were previously reported by Seichi et al. [6].

10-meter walk test

Spatiotemporal gait parameters and gait kinematics during 10-m walk test were assessed using a sensor-based three-dimensional motion analysis system (H-Gait system, Hokkaido University, Sapporo, Japan) with seven wearable sensor units (TSDN121, ATR-Promotions, Inc., Kyoto, Japan). The walk way has a 2m run off for the acceleration and deceleration before and after, in the 10-m trial. Participants performed 2 trials of 10-m walk with self-selected speed after 2 practice trials.

Gait assessment protocol is as follows. First, ten spherical markers are attached to the greater trochanters, the medial and lateral femoral epicondyles, and the medial and lateral malleoli (Fig. 2). Three static images to scale each participant are taken from the right, left, and front sides using a digital camera (EX-F1, CASIO COMPUTER CO., LTD, Tokyo, Japan). Then, the spherical markers are removed, and 7 sensor units are secured using Velcro bands with a pocket at sacrum, front aspect of mid-thigh, front aspect of mid-shank and front of the shoes. Sensor units are synchronized and recorded tri-axial acceleration and tri-axial gyro with sampling rate of 100 Hz. Before the 10-meter walk test, sensor calibration are performed for each participant in the upright and inclined position to calculate the initial inclination of each sensor [9]. Then, 10-m walk test started and ends with static standing phase that are required for the noise reduction processing of the sensor system [10].

Data analysis

Data analysis is performed using MATLAB (Math Works Inc., Natick, MA, USA) software with a customized motion analysis program. The thigh length, shank length, foot height and hip width are measured using the three static images [9]. The sensor coordinate system is calibrated to the global coordinate system using the gravitational acceleration vector during sensor calibration trials at upright and inclined positions [9]. Then, each sensor coordinate system is adjusted to each segment coordinate system using the inclination of each segment in three standing images [9]. Each sensor angle is expressed as angular displacement from upright standing using a quaternion, and angular displacement was determined the integral of angular velocity from the gyro sensor. Furthermore, the wire frame model was developed using scaling data and segment coordinate system to quantify the lower limb joint angle and spatiotemporal gait parameters [9]. In addition, ankle and knee joint horizontal plane trajectory angles are calculated (Fig. 3) [11]. These trajectory angles can sensitively detect the difference in gait kinematics between individual with and without knee OA compared with peak knee flexion or extension angles [11].

Each gait cycle was defined as a heel contact to the next heel contact. Heel contact and toe-off were determined by the peak angular velocity of the shank [9, 14]. Peak joint angles for each stance and swing phase were determined for hip, knee and ankle joints and were averaged for gait cycles except for the first and last cycles of 10-meter walk test. Spatiotemporal gait parameters included gait speed (m/s), cadence (steps/m) and step length (m).

Statistical analysis

One way analysis of variance (ANOVA) was conducted to compare demographics, spatiotemporal gait parameters and gait kinematics during 10-m walk test between the LS-stages. Differences in sex ratios between the LS-stages were tested with a chi-square test. Tukey HSD test was used as post-hoc pair-wise comparison. The level of significance was set to $P < 0.05$. All statistical analyses were performed using SPSS Statistics 22 (IBM Corporation, Armonk, NY, USA).

Results

As a result of the GLFS-25, the number of each LS stage was 69, 33 and 23 for stage 0 (Non-LS), LS-stage 1 and LS-stage 2, respectively (Table 1). There was no significant difference in gender, age, height, or weight among the groups. One-way ANOVAS showed significant differences in gait speed, cadence, and step length among groups (Table 2). Gait speed in LS-stage 2 was significantly lower than that in Non-LS and LS-stage1 ($P < 0.001$ and $P = 0.006$). Cadence and step length in LS-stage 2 were also significantly lower than those in Non-LS ($P = 0.027$ and $P = 0.001$). On the other hand, no difference was found between non-LS and LS-stage 1 regarding spatiotemporal gait parameters. Ankle joint horizontal plane trajectory angle was significantly differed among groups, while there was no between group difference in horizontal plane trajectory angle knee joint. Ankle joint trajectory angle in LS-stage 2 was significantly larger than non-LS ($P = 0.022$)

Table 1
Participants' characteristics for each LS stage

	Non-LS (n = 69)	**LS-stage 1 (n = 33)**	**LS-stage 2 (n = 23)**	***P* value**
Gender, n (male/female)	13/56	3/30	3/20	0.408
Age, years	70.5 (6.5)	73.7 (7.1)	73.1 (6.7)	0.135
Height, m	153.8 (7.3)	150.8 (7.9)	151.1 (6.7)	0.311
Weight, kg	51.2 (8.3)	54.1 (7.8)	53.6 (11.0)	0.482
$^{*}P < 0.05$ (vs Non-LS)				
$^{\dagger}P < 0.05$ (vs LS stage 1)				
LS: Locomotive syndrome				

Table 2
Comparisons of spatiotemporal gait parameters

	Non-LS (n = 69)	**LS-stage 1 (n = 33)**	**LS-stage 2 (n = 23)**	***P* value**
Spatiotemporal parameters				
Speed [m/s]	1.3 (0.2)	1.2 (0.2)	1.1 (0.2) *†	**< 0.001**
Cadence [steps/min]	120.6 (10.9)	120.6 (12.4)	111.4 (15.3)*	**0.027**
Step length [m]	0.78 (0.23)	0.71 (0.22)	0.52 (0.22)*	**0.001**
Angle between right and left knee trajectory [°]	17.2 (10.8)	19.7 (10.4)	19.5 (10.7)	0.469
Angle between right and left ankle trajectory [°]	5.9 (4.3)	8.0 (5.6)	8.5 (3.4)*	**0.022**
*$P < 0.05$ (vs Non-LS)				
†$P < 0.05$ (vs LS-stage 1)				
LS: Locomotive syndrome				

Kinematic analysis revealed significant differences among groups (Table 3). During stance phase, the peak hip extension and abduction angles differed among groups ($P = 0.003$ and $P = 0.003$). Post-hoc test showed that the peak hip extension angle was significantly smaller in LS-stage 2 compared with Non-LS and LS-stage 1 ($P = 0.002$). The peak hip abduction angle was significantly larger in Non-LS compared with LS-stage 1 and LS-stage 2 ($P = 0.006$ and $P = 0.048$). There was no other difference in peak joint angle during stance phase. During swing phase, the peak hip flexion and knee flexion angles during swing phase were differed among groups. The peak hip flexion angle was significantly smaller in LS-stage 2 than that in Non-LS and LS-stage 1 ($P = 0.026$, $P = 0.148$). The peak knee flexion angle was also significantly smaller in LS-stage 2 compared with Non-LS and LS-stage 1 ($P = 0.005$ and $P = 0.248$). No difference was found between Non-LS and LS-stage 1 during swing phase.

Table 3
Comparisons of gait kinematics

	Non-LS (n = 69)	**LS-stage 1 (n = 33)**	**LS-stage 2 (n =23)**	***P* value**
Peak joint angles during stance phase [°]				
Hip extension	9.5 (5.3)	7.9 (4.2)	4.2 (8.2)*†	**0.003**
Knee extension	2.2 (2.6)	2.3 (3.3)	1.7 (3.1)	0.745
Ankle dorsiflexion	10.2 (6.5)	10.4 (7.3)	9.0 (9.8)	0.771
Peak joint angles during swing phase [°]				
Hip flexion	34.2 (8.8)	30.6 (8.9)	28.5 (9.5)*	**0.018**
Hip abduction	7.9 (3.6)	5.6 (3.5)*	5.9 (3.0)*	**0.003**
Knee flexion	65.2 (18.7)	58.8 (19.7)	50.6 (18.5)*	**0.006**
Ankle planter flexion	21.3 (10.6)	19.4 (13.6)	20.5 (13.3)	0.976

*$P < 0.05$ (vs Non-LS)

†$P < 0.05$ (vs LS-stage 1)

LS: Locomotive syndrome

Discussion

In this present study, we first investigated the gait kinematics and spatiotemporal gait parameters during walking in the subjects with LS using a wearable sensor system. This study showed that subjects with LS-stage 2 had significantly lower peak hip extension angles during the stance phase compared to subjects with Non-LS. During the swing phase, subjects with LS-stage 2 had significantly lower peak flexion angles of hip and knee joints and higher the peak hip abduction angles. These decreased peak hip angles of extension and flexion and peak knee flexion angle were consistent with those of a previous study that assess the gait kinematics in the patients with knee OA [15, 16]. Therefore, it is possible that a certain number of subjects with LS-stage 2 might have knee OA, while we did not perform radiological evaluation of knee joints in the participants.

The present study revealed that walking speed, cadence, and step length were significantly lower in the subjects with LS-stage 2 compared to the subjects with Non-LS. These results were also consistent with those of a previous study that assess the spatiotemporal gait parameter in the subjects with knee OA [16, 17]. The GLFS-25, used to diagnose LS, is a subjective assessment that reflects the physical condition of the patient and the difficulty of daily living and social activities. Fifty percent of patients with LS stage 2 had some kind of restriction on daily living and social activities [6]. The subjects with LS-stage 2 in this study may have some difficulty in walking. LS-stage 2 group showed significantly different lower-limb kinematics compared with Non-LS group including smaller hip extension, hip flexion and knee flexion. The intervention based on these kinematic characteristics would be useful to improve the locomotive ability for individuals classified LS-stage 2.

On the other hand, LS-stage 2 and LS-stage 1 groups had significantly lower peak hip abduction angles during the swing phase compared to the Non-LS group. However, these differences between groups were within the measurement error [12]. Therefore, there is no significant difference in the gait kinematics of the hip joint on the frontal plane, and the gait kinematics in the sagittal plane should be focused on in order to detect the difference between LS and Non-LS.

In this study, the angle between trajectory lines of bilateral ankles was significantly greater in the subjects with LS-stage 2 compared to the subjects with Non-LS. The trajectory line of the ankle in the horizontal plane reflects to the combination of the kinematics of abduction-adduction and rotation in hip and knee joints during each gait cycle [11]. While it remains uncertain why the angle between trajectory lines of right and left ankles is significantly larger in the subjects with LS-stage 2 than Non-LS, the angle between trajectory lines of bilateral ankles may be a useful target during gait training as an intervention of based on these kinematic characteristics for individuals with advanced locomotive syndrome.

This study has several limitations. First, the severity classification of LS was based on the results of GLFS-25. In some other previous studies, the Stand-up Test and the 2-Step Test have assessed the severity classification of LS. The results may have differed depending on the evaluation index used, which may have affected the determination of LS [18]. Second, the subjects of this study were only local residents who utilized a public health promotion facility. It was unclear whether the results of this study apply to other local residents who did not utilize a public health promotion facility. Finally, because this study was a cross-sectional study, it was unclear the causal relationship between the onset of LS and differences in lower limb kinematics during walking.

Conclusions

In this study, we first investigated the gait kinematics and spatiotemporal gait parameters during walking in the subjects with LS using a wearable sensor system. This study showed that subjects with LS-stage 2 had significantly lower peak hip extension angles during the stance phase compared to subjects with Non-LS. During the swing phase, subjects with LS-stage 2 had significantly lower peak flexion angles of hip and knee joints and higher peak hip abduction angles. The intervention based on these kinematic characteristics would be useful to improve the locomotive ability for individuals classified in LS-stage 2.

Abbreviations

LS: Locomotive syndrome

GLFS-25: 25-question Geriatric Locomotive Function Scale

OA: osteoarthritis

Declarations

Ethics approval and consent to participate: All methods were carried out in accordance with relevant guidelines and regulations. This study received ethical approval from the Institutional Review Board of the Faculty of Health Sciences at Hokkaido University (18-50), and written informed consent was obtained from all study participants.

Consent for publication: Not applicable.

Availability of data and materials: The datasets generated and/or analyzed during the current study are not publicly available due to limitations of ethical approval involving the patient data and anonymity but are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: YS, YK, KN, AN and SO collected the data. YS, YK, TI, ST, MS and HT designed the study and drafted the manuscript. YS, YK, RT, SY and TS performed data processing. All authors read and approved the final manuscript.

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Figures

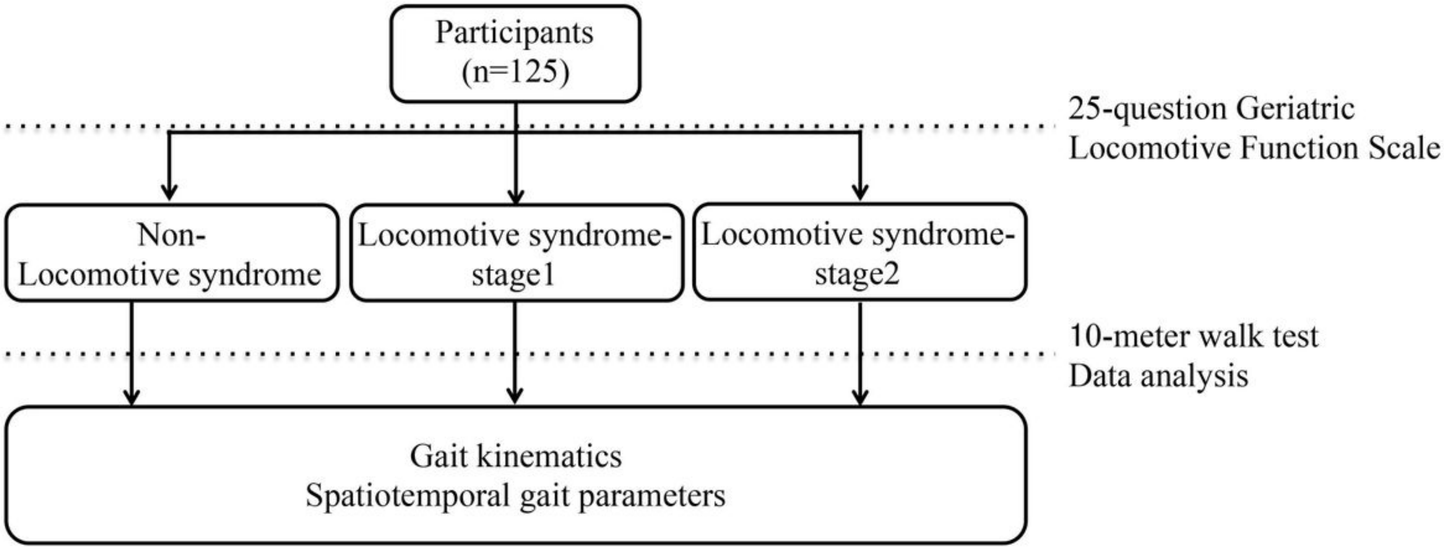

Figure 1

Study design.

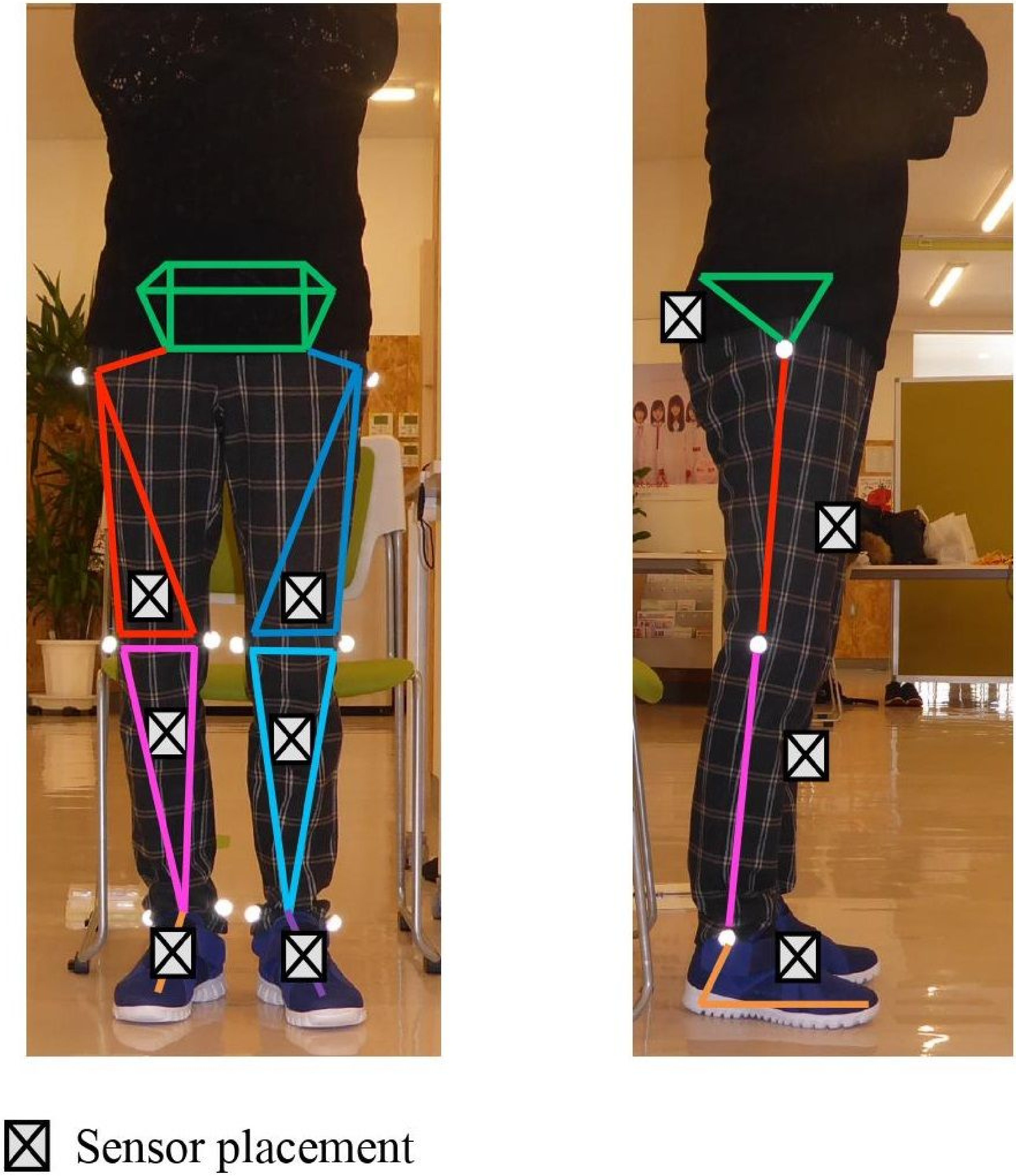

Figure 2

Sensors and marker placement

Sensor units were attached to seven body segments of the lower limbs and pelvis. Markers were placed at bilateral great trochanter, medial and lateral femoral epicondyles and medial and lateral malleoli.

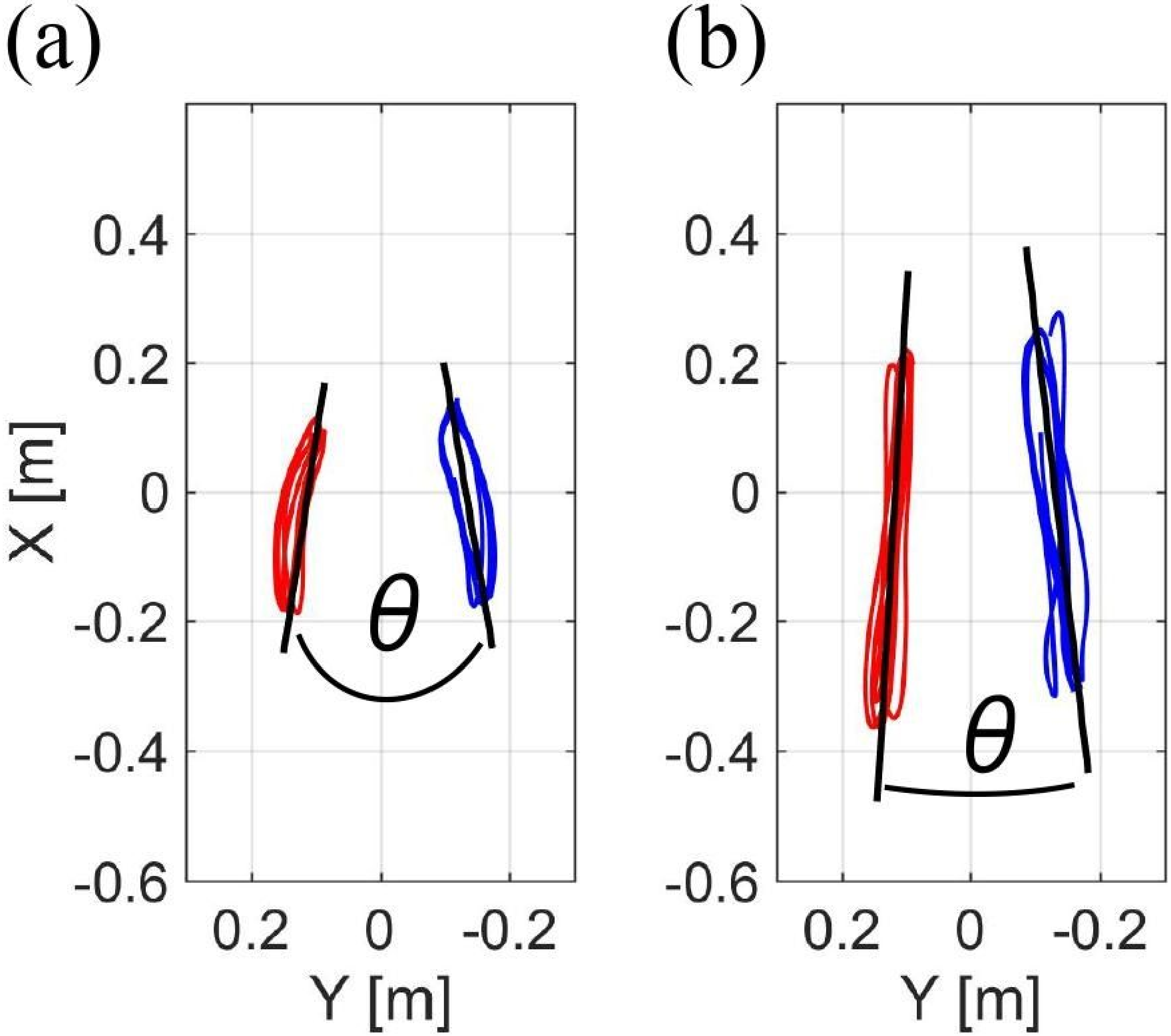

Figure 3

Knee and ankle joint horizontal plane trajectory angles

The knee and ankle joint horizontal plane trajectory angles are formed by approximate lines of the trajectory on horizontal plane for knee joint centers (a) and ankle joint centers (b), respectively.