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A Study on the Contribution of Medial and Lateral Longitudinal Foot Arch to Human Gait

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Abstract—**This study aimed to investigate the contribution of medial longitudinal arch and lateral longitudinal arch in human gait and to study the correlation between foot features and gait characteristics. The foot arch plays a significant role in human movements, and understanding its contribution to spatiotemporal gait parameters is vital in predicting and rectifying gait patterns. To serve the objectives, the study developed a new foot feature measurement system and measured the foot features and spatiotemporal gait parameters of 17 young healthy subjects without any foot structure abnormality. The foot-feature parameters were measured under three movement conditions which were sitting, standing, and one-leg standing conditions. The spatiotemporal gait parameters were measured at three speeds which were fast, preferred, and slow speeds. The correlation study showed that medial longitudinal arch characteristics were found to be associated with temporal gait parameters while lateral longitudinal arch characteristics were found to be associated with spatial gait parameters. The developed system not only eases the burden of manual measuring but also secures accuracy of the collected data. Inviting variety of subjects including athletes and people with abnormal foot structures would extend the scope of this study in the future. The findings of this study break new ground in the field of the foot- and gait-related research work.**

Clinical Relevance—**This study demonstrated that the medial longitudinal arch and lateral longitudinal arch characteristics were related to the temporal and spatial gait parameters, respectively. These underlying findings can be applied to investigate relationships between foot abnormality and gait characteristics.**

I. Introduction

A foot is the most distal segment of a body that reaches the ground first and enables a steady rollover and force transaction between the foot and ground. When walking or running, this interaction between the foot and ground makes a unique and consistent plantar load distribution and an excursion pattern of center of pressure (CoP) [1]. However, this pattern could easily stray from the normal path when the structural and morphological characteristics of a foot change which may trigger foot or body injuries [2, 3]. The arch of a foot is one of many structural characteristics of a foot and it enables natural weight bearing by absorbing the shock from the ground [4]. The windlass mechanism of a foot arch not only provides propulsion force needed to push the body forward but also stabilizes the posture by adjusting the tension of the arches [1, 3]. The foot arch comprises the medial longitudinal arch (MLA), lateral longitudinal arch (LLA), and transverse arch and can be classified into the high, normal, and low types according to the height of the navicular bone [5]. Any morphological or structural abnormality of a foot arch can hinder proper foot plantar load distribution and by doing so can alter the kinematic and kinetic pattern of the whole-body dynamics. In such cases, the risk of tissue and bone injuries increases [1, 2, 6, 7].

Multiple studies have investigated the effects of arch types on human movements [1, 3, 8-12]. Chang *et al*. have investigated the relationships between the foot arch volume measured at static conditions using three-dimensional (3D) foot scanners and the plantar load distribution while walking. The study found that people with low foot arch are more prone to foot injuries since the weight distribution tend to center on medial side of a foot [12]. Another study that investigated the kinematic difference between the normal- and low-arched groups demonstrated that the low-arched group has an increased external hip rotation and a decreased forefoot supination angle. Yet, no significant difference in spatiotemporal gait parameters was found [9-11]. Hertelet *et al*. compared the foot pressure distribution in static single-limb support (SLS) and dynamic walking conditions and suggested that the foot pressure distribution in static condition can predict a gait pattern [13]. Zumbrunn *et al*. explored the postural control ability of healthy individuals with various foot types in the single-leg stance and claimed that the subjects with low foot arch used significantly larger CoP excursion area compared to those with average arch, indicating that the low-arched group have relatively poor ability to maintain balance [14].

Although these studies have advanced the understanding of the foot arch and its contribution to human movements, most studies mainly focused on MLA morphology and lacked consideration of LLA. However, a recent study conducted by Fukano and Fukubayashi discovered that the reaction against landing impact of MLA distinctively differ from that of LLA and that each longitudinal arch has a different deformation pattern; MLA has a larger translational motion, while LLA has a greater rotational motion when absorbing shock [15]. Besides, our recent research that investigated the correlation of a foot structure and postural stability has demonstrated that CoP excursion in anterior-posterior (AP) direction was positively related to the MLA characteristics whereas a medio-lateral (ML) and overall CoP excursion were positively related to the LLA characteristics. This can be a clear indication that LLA does play a role in maintaining a body balance and the role of LLA is different from that of

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MLA [16]. Thus, LLA should be considered when investigating foot features that affect human movement.

This study aims to found the distinctive roles of MLA and LLA in human gait and to further investigate their association with spatiotemporal gait parameters. We hypothesize that i) MLA and LLA have a different movement pattern in various movement conditions, and MLA and LLA can move independently despite their physical constraints and ii) the roles of MLA and LLA in human gait are different. The discovered relationship between the foot features and human gait would serve as referential data in various fields, such as human motion analysis, gait rehabilitation regimen, and fabrication of personalized insole design.

II. Materials and Methods

A. *Foot feature measurement system and spatiotemporal gait parameter measurement*

A foot feature measurement system (FFMS) comprises a runway type scanning stage of 200 cm (length) × 70 cm (width) × 45 cm (height) and performs measurement and analysis simultaneously (Fig. 1(a)) [17]. A scanning spot (40 cm in length × 35 cm in width) made of transparent acrylic panel with 4-uniaxial force sensors at each corner was installed in the middle of the scanning stage. The scanning spot calculates CoP and the single RGB-depth camera (Intel Realsense F200) placed underneath the panel captures the depth image of a sole. The collected foot shape and CoP data get time-synchronized and stored in the server. While the subjects were performing various movement tasks on the scanning spot, FFMS gets the shape of the sole in the form of a 3D point cloud with 60 frames per second rates. Based on this information, the analysis system calculates the foot anatomical features, such as foot length and foot width and the heights and angles of MLA and LLA arch curves, which are then provided to the testers (Fig. 1(b)) [18].

A commercialized inertial measurement unit (IMU) equipped with motion-capture sensors (Xsens MVN, Enschede, Netherland) was adopted to assess the spatiotemporal gait parameters (Fig. 1(c)) [19, 20]. While the subjects were performing various movement tasks, this motion-capture system collected data on accelerations, angular velocities of body segments and based on the collected data the joint angles, travel distance as well as gait event, such as the heel-strike (HS) and toe-off (TO) times were calculated [20-22]. The extraction process and detailed definitions of the foot-feature parameters and spatiotemporal gait parameters are presented in the "*C. Foot-feature parameters and spatiotemporal gait parameters*" section.

B. *Participants and experimental protocol*

A total of 17 healthy subjects with an age (mean ± SD) of 28.08 ± 2.78 years participated in this study. Their height and weight (mean ± SD) were 174.31 ± 8.00 cm and 77.15 ± 14.31 kg. The subjects were excluded if they had any muscular-skeletal injuries, structural abnormality in their foot, medical insoles, or any clinical history of ankle, knee, and hip joints injuries. The experiment was conducted on the prior consent from all subjects, and informed consent have been obtained from all participants. There was no violation of human rights throughout the experiment. This study was approved by the Institutional Medical Ethics Review Board at Korea Institute of Science and Technology, and all methods were performed in accordance with the relevant guidelines and regulations.

Prior to the experiment, an experienced experimenter marked the first metatarsophalangeal (MTP) bone and the fourth MTP bone of all subjects by palpation. The experiment comprised two sessions: 1) a scanning session that extracts foot-feature parameters and 2) a gait session that measures spatiotemporal gait parameters. The dominant foot was measured in the scanning session and the spatiotemporal gait parameters were calculated based on the same dominant foot.

The scanning session included three movement conditions: 1) sitting, 2) standing, and 3) one-leg standing (OLS) conditions. For the sitting and standing conditions, all subjects were instructed to maintain the sedentary position while sitting on a chair with their both limbs' ankle and knee joint angles at 90° as shown in Fig. 2 and slowly stand up while the foot images were obtained on the scanning spot for five seconds. As for OLS condition, all subjects were asked to balance their body as stable as possible on their dominant limb for 10 seconds while the knee and hip joints of the other

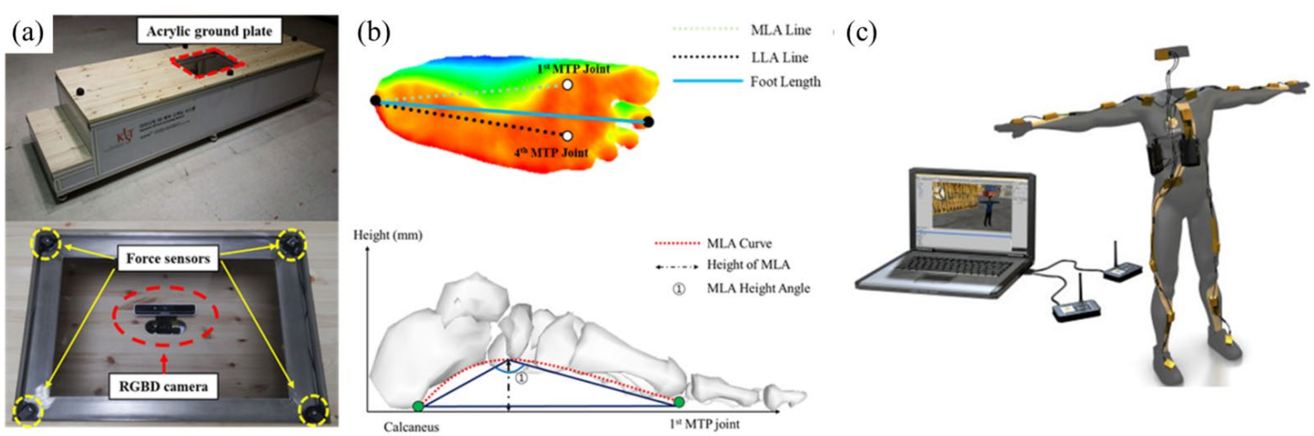

Figure 1. (a) Overall foot feature measurement system (FFMS) that consists of a scanning stage for foot shape measurement. FFMS has a transparent scanning spot in the middle of the walkway with four uniaxial force sensors at the corners of transparent acrylic panel to calculate center of pressure and a single RGB depth camera. (b) Depth image of the foot and defined foot feature parameters such as foot length, height and height angles of medial longitudinal arch (MLA) and lateral longitudinal arch (LLA) curves and (c) a motion-capture system (Xsens MVN) used for this study.

Figure 2. Scanning session including three movement conditions: sitting, standing, and one-leg standing.

limb were lifted and maintained 90° angle.

The gait experiment was performed using the commercialized gait analysis system, which comprised 13 IMU sensors. As this study solely focused on the lower limb motions, only 7 of the 13 sensors were used. Following the system manual, each sensor was attached on the foot, shank, thigh, and pelvis of a subject. The gait session comprised three speeds: 1) fast, 2) preferred, and 3) slow speeds. First, the subjects were instructed to walk for a 30-m straight path at their preferred walking speed. Then they were instructed to walk the same path slowly and fast. The gait which were 20 ± 5% faster and slower than the preferred speed was considered as the slow and fast walk of the subjects. A total of 10 strides in the middle of the walkway were used for analysis. Any unstable strides at the first and last five meters were excluded.

C. *Foot-feature parameters and spatiotemporal gait parameters*

The developed FFMS collected foot-feature parameters, such as foot length, heights of MLA and LLA curves, and height angles of MLA and LLA curves (Fig. 1(b)). The straight line connecting the edge of the second toe to the heel imprints on the depth camera image was defined as the foot length, and the lines connecting the first MTP joint and the fourth MTP joint from the edge of heel were defined as MLA and LLA lines, respectively. To extract MLA curves, MLA line was projected onto the plantar surface of the foot. The apex of MLA curve was used as the MLA height. Then MLA height angle was calculated. Not only the heights but also the location of apex determined the height angle. The same was applied to get LLA parameters.

The HS and TO times at each speed were detected using the motion analysis system. From the detected gait event information, spatiotemporal gait parameters were calculated. Stride time is defined as the time elapsed between a HS and a consecutive HS of the dominant foot, whereas step time is defined as the time elapsed between a HS and a consecutive HS of the other foot. As for stance and swing times, the time from the point of HS to TO and that from TO to a consecutive HS were respectively applied. SLS time is defined as the amount of time spent when one limb stayed on the ground, whereas double-limb support (DLS) time is defined as the amount time spent when both limbs stayed on the ground. The number of steps per minute was used as cadence. Stride and step length were calculated based on the temporal parameters and the travel distance. Gait velocity is calculated as the value of 30 meters divided by the total amount of time to reach the end point. Stride and step lengths were normalized by the height of each subject [23-25].

D. *Statistical analysis*

One-way analysis of variance (ANOVA) was performed to seek significance in parameters under different experimental settings. The correlation analysis between foot-feature parameters and spatiotemporal gait parameters followed to find possible association between the two parameters. One on one comparison of each foot-feature parameter with each gait parameter confirmed the association between them using bivariate correlation analysis. The significance level was set at $P < 0.05$.

III. Results

A. *Statistics on foot-feature parameters and spatiotemporal gait parameters*

The results of one-way ANOVA with Tukey's post-hoc test for the foot-feature parameters and spatiotemporal gait parameters are summarized in Table I. The foot length, MLA and LLA heights and height angles were chosen as foot-feature parameters and the stride length and time, step length and time, cadence, gait velocity, stance time, swing time, percentage of stance phase, and SLS and DLS times were considered as spatiotemporal gait parameters. The MLA height was lower in standing condition than that in sitting condition, while no statistical significance was found in other variables (Table I).

The stride and step lengths as well as gait velocity decreased at slow and preferred speed compared to those at fast speed. All temporal gait parameters except for the percentage of stance phase significantly decreased at fast speed whereas the spatial parameters increased under the same speed condition (Table I). Increased gait velocity was found to be associated with increased spatial gait parameters and decreased temporal gait parameters.

B. *Correlation between MLA and spatiotemporal gait parameters*

The correlation coefficients between the foot-feature parameters for MLA and spatiotemporal gait parameters are summarized in Table II. The correlation coefficients between the foot-feature parameters for MLA and temporal gait parameters were higher in the OLS condition compared to the sitting and standing conditions. The MLA height angle in the OLS condition was negatively correlated with the stride time, step time, SLS time, stance time, and cadence at the fast- and preferred-speed walking. The scatter plots in Fig. 3 show the relationships between the MLA height angle in the OLS condition and temporal gait parameters along with the correlation coefficients.

C. *Correlation between LLA and spatiotemporal gait parameters*

The correlation coefficients between the foot-feature parameters for LLA and spatiotemporal gait parameters are summarized in Table II. The correlation coefficients between the foot-feature parameters for LLA and spatial gait parameters were higher in the OLS condition compared to the

TABLE I. STATISTICS ON THE FOOT-FEATURE PARAMETERS IN SITTING, STANDING, AND ONE-LEG STANDING CONDITIONS AND THE SPATIOTEMPORAL GAIT PARAMETERS AT FAST-, PREFERRED-, AND SLOW-SPEED WALKING

Foot-feature parameter	**Movement condition**		
	Sitting	***Standing***	***One-leg standing***
Foot length (mm)	243.14 ± 8.61	246.77 ± 8.52	244.98 ± 8.74
MLA[a] height (mm)	12.52 ± 3.25	9.87 ± 3.07[†]	10.68 ± 2.60
MLA[a] height angle (°)	167.37 ± 4.67	169.23 ± 4.68	169.03 ± 4.24
LLA[b] height (mm)	5.19 ± 1.62	4.76 ± 1.24	5.00 ± 1.01
LLA[b] height angle (°)	170.11 ± 6.27	166.14 7.59	161.58 ± 19.31
Spatiotemporal gait parameter	**Walking speed**		
	Fast	***Preferred***	***Slow***
Stride length (m)	0.93 ± 0.07	0.85 ± 0.06[**]	0.76 ± 0.05[**,##]
Step length (m)	0.49 ± 0.05	0.44 ± 0.04[*]	0.41 ± 0.03[**,##]
Stride time (s)	1.00 ± 0.84	1.07 ± 0.07	1.32 ± 0.21[**,##]
Step time (s)	0.52 ± 0.04	0.55 ± 0.04	0.70 ± 0.12[**,##]
Cadence (step/min)	120.80 ± 9.49	112.79 ± 7.16	93.13 ± 13.45[**,##]
Gait velocity (m/s)	1.64 ± 0.22	1.39 ± 0.17[*]	1.03 ± 0.21[**,##]
Stance time (s)	0.56 ± 0.04	0.59 ± 0.04	0.74 ± 0.13[*,#]
Swing time (s)	0.44 ± 0.05	0.48 ± 0.04	0.57 ± 0.09[**,##]
% of stance phase	55.78 ± 1.49	55.28 ± 1.14	56.29 ± 1.34
SLS[c] time (s)	0.44 ± 0.04	0.46 ± 0.04	0.60 ± 0.11[**,##]
DLS[d] time (s)	0.12 ± 0.01	0.13 ± 0.02	0.15 ± 0.03[**,#]

a. Medial longitudinal arch; b. Lateral longitudinal arch; c. Single-limb support; d. Double-limb support.

† Statistical difference from the sitting condition, $P < 0.05$.

* Statistical difference from the fast-speed walking condition, $P < 0.05$.

** Statistical difference from the fast-speed walking condition, $P < 0.001$.

\# Statistical difference from the preferred-speed walking condition, $P < 0.05$.

\#\# Statistical difference from the preferred-speed walking condition, $P < 0.001$.

Data are presented as the mean ± SD.

sitting and standing conditions. The LLA height angle in the OLS condition had a positive correlation with the stride length, step length, and gait velocity at the fast- and preferred-speed walking. The scatter plots in Fig. 4 show the relationships between the LLA height angle in the OLS condition and spatial gait parameters along with the correlation coefficients.

IV. DISCUSSION

Despite the well understood importance of LLA in human movements, the contribution of LLA to human movements has been neglected for long due to laborious and complicated measurement process. To cope with the challenge, we developed a new type of FFMS that can observe both MLA and LLA curves as well as their alterations in various experimental conditions. The newly developed FFMS not only eases the burden of measuring but also provides abundant data on foot features, such as the foot length, width, and height and angles of MLA and LLA curves. The proposed system showed reasonable accuracy compared to that of the manual measurement. Besides, the system can provide foot images at 60 fps. Hence, precise changes in the foot arch structure under various movement conditions can be observed. The feasibility, accuracy, and repeatability of the developed FFMS can be found in our previous research work [17].

While MLA height angle increased in weight bearing situations such as standing and OLS conditions, the LLA height angle decreased in the same situation (Table I). This may serve as a clear proof demonstrating that MLA and LLA work independently despite their physical proximity. In that, the first hypothesis of this study was verified. The changes of foot-feature parameters in weight bearing situations, which were addressed by many other studies, were also observed in this study. As summarized in Table I, the MLA heights lowered in the standing and OLS conditions. These findings agree with the results of previous study that reported the changes in foot arch heights in weight bearing and non-weight bearing situations [26]. Wright *et al*. reported that a foot is not a rigid base of support but a compliant component and MLA controls the whole body balance by regulating its arch characteristics [27]. However, what this study has found about the changes of foot-feature parameters except for the MLA height was only a mild tendency and it lacks statistical significance due to high inter-individual variability.

The correlation between the MLA and temporal gait parameters that this study found suggests that the MLA characteristics can represent the temporal gait characteristics. As shown in Fig. 3, the foot-feature parameters for MLA are highly associated with the temporal gait parameters. It can be said that the wider the MLA height angle is, the shorter the stay of the lower limb on the ground becomes. It indicates that individuals with lower MLA height and wider MLA height angle in OLS condition have relatively shorter stance and SLS times which result in shorter stride and step times during walking.

In terms of LLA, the correlation was found rather with the spatial gait parameters than with the temporal gait parameters. As Fig. 4 shows, the LLA height angle in the OLS condition was closely related with the stride length, step length, and gait velocity at fast and preferred speeds. The wider the LLA height angle was, the longer the stride and step lengths were and the faster the gait velocity was. A possible explanation of this can be found in the research conducted by Hunt and Ledoux [28, 29]. In their research studying the correlation between foot arch type and plantar load distribution, they demonstrated that the plantar load is concentrated in the subhallucal and first MTP areas in the flat foot group. In such cases, the flat foot group showed greater peak plantar-flexor ankle moment at push-off. These dynamics may have influenced the spatial characteristic of gait and have resulted in longer stride and step lengths and faster walking velocity. Although a direct comparison may not be plausible since the two studies have different subject groups and LLA was not considered in the cited study, the potential of the suggested dynamics influence the results of this study cannot be fully ruled out. By demonstrating that MLA is correlated with temporal gait parameters whereas LLA is correlated with spatial gait parameters, the findings verify the second hypothesis of this study claiming that the roles of MLA and LLA in human gait are different.

Although this study has overcome the challenges of measuring LLA characteristics in various movement conditions and successfully demonstrated their separate involvement in human gait, the study bears several inevitable limits. The first is that the study was not able to invite a wide group of subjects. All the recruited subjects were young and healthy and had no structural abnormalities in their foot. Accordingly, little attention was paid to various foot types.

TABLE II. CORRELATION BETWEEN THE FOOT-FEATURE PARAMETERS AND SPATIOTEMPORAL GAIT PARAMETERS

		Correlation coefficient																																
		Stride length			***Stride time***			***Step length***			***Step time***			***SLS[a] time***			***DLS[b] time***			***Swing time***			***Stance time***			***Cadence***			***% of stance phase***			***Gait velocity***		
		F[c]	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***	***F[c]***	***P[d]***	***S[e]***
Sitting	Foot length	.40	.55*	.37	-.09	-.13	-.36	.30	.44	.29	-.15	-.15	-.39	-.10	-.08	-.44	-.01	-.20	.22	-.07	-.06	-.36	-.10	-.18	-.36	.10	.15	.40	-.00	-.19	-.16	.35	.46	.41
	MLA[f] height	-.10	-.41	-.28	.25	.30	.28	-.07	-.33	-.32	.30	.32	.25	.23	.26	.27	.22	.16	.06	.18	.22	.30	.31	.34	.26	-.25	-.31	-.29	.09	.15	.04	-.11	-.30	-.19
	MLA[f] height angle	.03	.44	.40	-.36	-.39	-.28	.00	.30	.43	-.41	-.47	-.26	-.35	-.44	-.27	-.26	-.08	-.13	-.25	-.26	-.29	-.44	-.48	-.27	.36	.41	.29	-.13	-.31	-.08	.11	.34	.22
	LLA[g] height	.07	-.09	.03	.06	.08	.04	.13	.02	.12	.14	.16	.06	.16	.13	.04	-.20	.00	.11	.03	.01	.01	.09	.13	.06	-.04	-.07	-.01	.07	.19	.20	.13	.04	.14
	LLA[g] height angle	.22	-.00	.10	.06	.21	.27	.20	-.07	.31	.05	.14	.31	.03	.10	.33	-.01	.11	.05	.08	.24	.20	.03	.16	.30	-.01	-.19	-.23	-.09	-.18	.41	.15	-.06	.02
Standing	Foot length	.46	.45	.30	-.26	-.21	-.41	.37	.36	.29	-.32	-.22	-.40	-.26	-.07	-.44	.03	-.36	.13	-.24	-.14	-.44	-.25	-.26	-.37	.28	.23	.44	.11	-.17	.00	.47	.44	.43
	MLA[f] height	-.10	-.34	-.11	.31	.26	.14	.02	-.18	-.13	.45	.37	.11	.38	.27	.14	.19	.21	-.06	.16	.10	.16	.44	.38	.12	-.29	-.25	-.12	.30	.41	-.00	-.11	-.21	.03
	MLA[f] height angle	.05	.20	.09	-.46	-.32	-.04	-.06	-.03	.09	-.61**	-.50*	-.02	-.56*	-.40	-.05	-.07	-.18	.10	-.32	-.09	-.07	-.58*	-.49*	-.02	.47	.32	.02	-.21	-.60*	.06	.21	.20	-.08
	LLA[g] height	.02	-.15	.09	.06	.08	-.07	.06	-.06	.15	.11	.11	-.07	.15	.05	-.10	-.17	.16	.13	.03	.01	-.09	.09	.13	-.06	-.06	-.09	.08	.06	.18	.13	.04	-.06	.21
	LLA[g] height angle	.35	.27	.40	.04	-.01	.06	.28	.22	.28	.05	.02	.04	-.04	-.04	.02	.09	.08	.12	.08	-.03	.09	-.01	.00	.04	.03	.07	.01	-.12	.05	-.08	.32	.31	.22
One-leg standing	Foot length	.44	.39	.15	-.13	-.13	-.33	.34	.36	.10	-.20	-.11	-.34	-.15	.01	-.38	.04	-.32	.13	-.12	-.09	-.34	-.14	-.15	-.31	.11	.12	.32	.03	-.09	-.08	.37	.35	.29
	MLA[f] height	-.08	-.29	-.18	.40	.37	.18	.00	-.15	-.27	.52*	.46	.13	.43	.35	.15	.24	.20	.00	.27	.22	.23	.52*	.46	.14	-.39	-.36	-.17	.21	.34	-.14	-.15	-.23	-.05
	MLA[f] height angle	.04	.30	.26	-.54*	-.48	-.18	-.03	.11	.33	-.67**	-.62**	-.13	-.57*	-.53*	-.16	-.26	-.16	.02	-.39	-.27	-.22	-.66**	-.61**	-.14	.54*	.48	.16	-.18	-.49*	.12	.22	.31	.08
	LLA[g] height	-.12	-.36	-.19	.24	.25	.22	-.08	-.29	-.16	.28	.22	.21	.26	.13	.19	-.11	.30	.23	.23	.18	.22	.22	.28	.22	-.25	-.27	-.23	-.11	.13	.13	-.14	-.27	-.11
	LLA[g] height angle	.60*	.61*	.47	-.08	-.23	-.14	.56*	.62**	.38	-.04	-.10	-.15	-.13	-.13	-.16	.16	-.06	.01	-.08	-.28	-.14	-.07	-.16	-.15	.10	.26	.21	.06	.22	-.11	.52*	.61**	.36

a. Single-limb support; b. Double-limb support; c. Fast-speed walking; d. Preferred-speed walking; e. Slow-speed walking; f. Medial longitudinal arch; g. Lateral longitudinal arch.

* Statistical significance of $P < 0.05$.

** Statistical significance of $P < 0.01$.

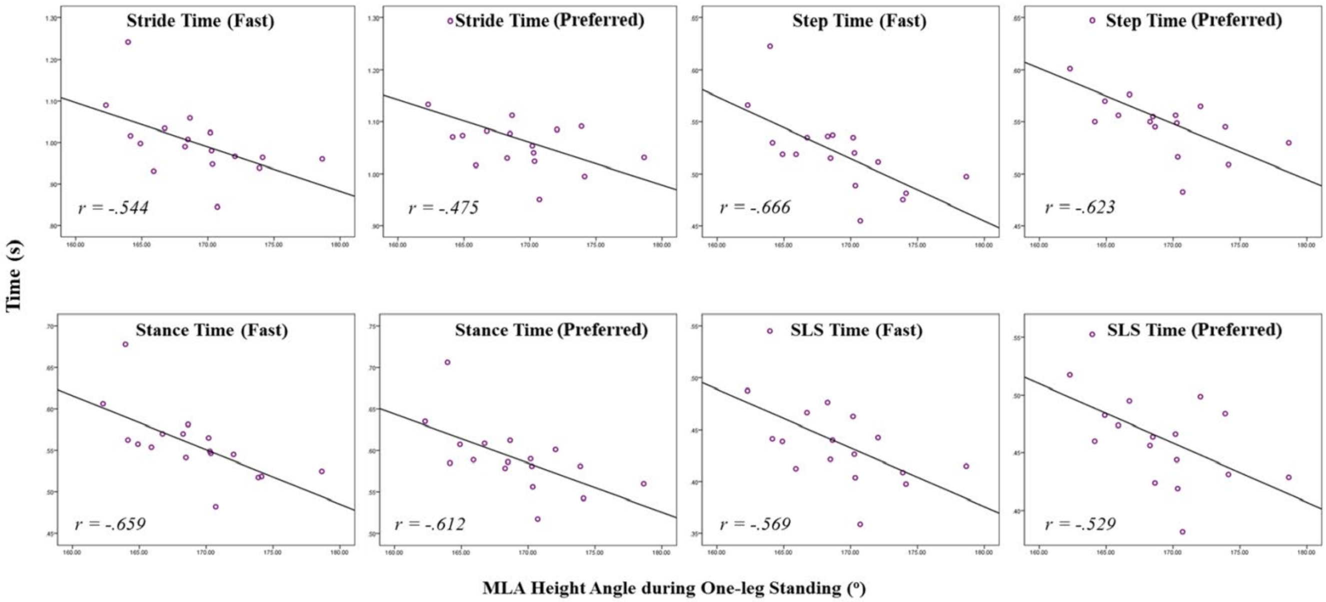

Figure 3. Correlation between medial longitudinal arch (MLA) height angle in one-leg standing condition and temporal gait parameters at preferred- and fast-speed walking.

The second is the inherent error of the depth camera embedded in the FFMS influencing the results of this study. Yet, when the measurements of the developed FFMS was compared with those of the manual system, little difference was found and the accuracy and repeatability of the system was evaluated in our previous study [17].

Despite the limits mentioned above, this study was the first to demonstrate the individual involvement of LLA and MLA in human gait and can well serve as a referential study. Inviting more variety in subject groups, such as athletes and people with abnormal foot structures, would extend the scope of this study.

V. Conclusion

This study aimed to investigate the contribution of MLA and LLA in human gait and demonstrated that MLA and LLA moves independently despite their physical proximity and that the MLA characteristics are related to temporal gait parameters while the LLA characteristics are related to spatial gait parameters. The newly developed FFMS made the measurement of the foot characteristics possible not only in static situations but also in moving conditions such as standing and OLS and enabled the simultaneous measurement of the MLA and LLA characteristics. The findings contribute to the understanding of complicated dynamics and

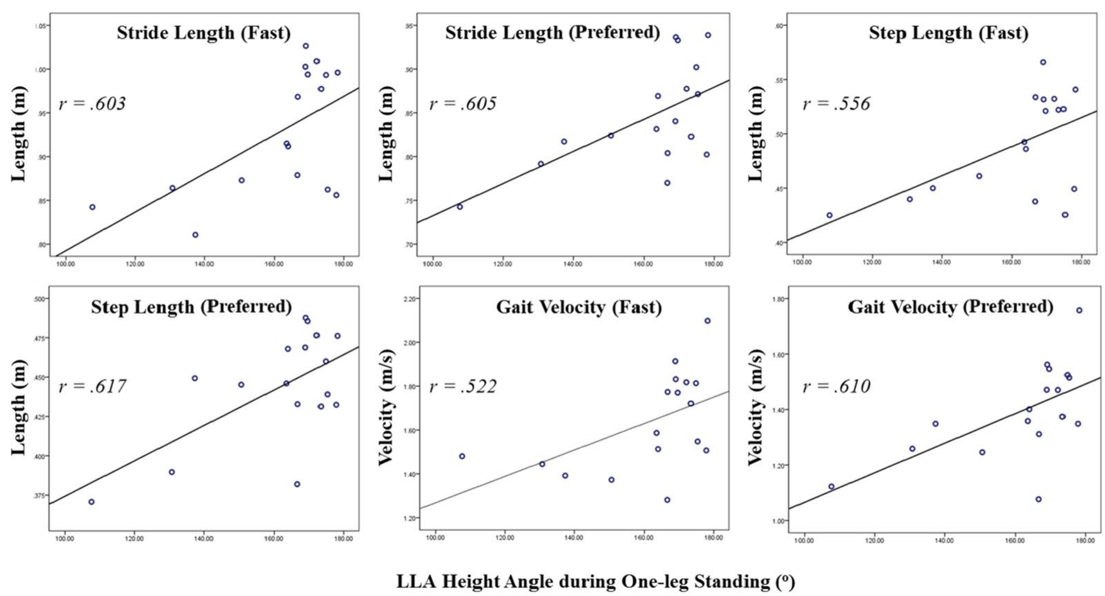

Figure 4. Correlation between lateral longitudinal arch (LLA) height angle in one-leg standing condition and spatial gait parameters at preferred- and fast-speed walking.

involvement of MLA and LLA in human gait and can serve as a preliminary study investigating the relationship between foot abnormality and gait characteristics.

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