Gait Analysis for Elderly People with Visual Impairment using Plantar Pressure Measurement

Ji-Yong Jung, Chang-Min Yang, and Jung-Ja Kim

***Abstract*—**Independent walking for elderly people with visual impairment is one of the important things in their daily lives. Accordingly, the objective of this study is to understand the gait characteristic of elderly people with visual impairment using plantar pressure distribution analysis. Ten male subjects who are visually impaired were recruited from the Korea Blind Union. Experimental procedure was divided into two conditions: walking without the white cane and with the white cane. The plantar pressure distributions were assessed during walking at a comfortable speed along a 10 m walkway. All plantar pressure distributions were subdivided into six regions of masks and five phases, and these data were analyzed for the force and pressure. The results showed that the maximum force and mean pressure of the right side increased while the peak pressure of that side decreased significantly. In addition, there was association with the foot regions and stance phase during walking both without and with the white cane. This paper suggest that gait and postural balance pattern of elderly people with visual impairment could be influenced by walking assistive device. Therefore, more researches are needed based on the gait characteristic to develop new types walking assistive device and provide appropriate rehabilitation strategies for people with visual impairment.

***Keywords*—**Visual impairment, elderly people, gait analysis, plantar pressure distribution.

I. INTRODUCTION

VISION plays an important role in maintaining one's balance during locomotion due to it provide significant information on the current location, direction, and environment. Especially, vision loss or visual impairment, which is defined as a decreased ability to see, can negatively influence on quality of human life with regard to physical activity such as driving, socializing, and walking [1]. Individuals with no usable vision or visual impairment have a difficulty when walking because of limited information on the spatial data. The visually impaired people experience inconvenience when walking.

Independent ambulation plays an important role in the self-concept formation and confidence for individuals with visual impairment. The white cane is the most typical walking assistive device that is employed by individuals who are visually impaired for physical stability and safety during individual walking [2]. It is a simple device which is used to extend tactile sensation primitively of user for delivering information by contacting directly the obstacles in the front side. However, the white cane is hard to detect objects which are located in a low position on the ground during walking.

Today, high tech devices which are equipped with various sensors are being developed through dramatic development of IT technology. Basically, many sensors, including laser, infrared ray, and ultrasound sensor, were implanted in the traditional white cane for scanning the surrounding environment [3]. Mobility feedback systems were developed to guide safely the user by providing sound or vibration signal [4]. Although, recently, various walking assistive devices with improved functionality have been developed to remedy disadvantage of the white cane, most of these devices are not considered the characteristics of gait and balance in individuals with visual impairment. In order to improve the walking assistive device with sensors, it is necessary to consider the effectiveness of developed devices for user [5].

According to the World Health Organization (WHO), there are an estimated 285 million people (blind: 39 million, low vision: 246 million) who are visually impaired. Of these individuals with visually impaired, 84% will be aged 50 years or more [6]. With the increase in age of people, a decrease in postural balance has been occurred. Complex problems such as decreased physical performance, mobility, cognitive ability, sensibility, and psychological change can affect negatively on gait of elderly people with visual impairment. Balance and mobility assessment is very important factor to provide the quality of rehabilitation process for elderly people with visual impairment [7]. Therefore, it is essential to assess the change in biomechanical gait characteristic between before and after using a device for development walking assistive device to improve gait ability of elderly people with visual impairment [8].

Commonly, pressure sensors, which has high sensitivity and linear characteristics, are utilized to provide the information about postural balance and gait patterns by converting electric signal into physical output in various clinical and research fields, involving gait analysis and biomechanics in sports and

This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1A6A3A11934555) and the Ministry of Science and ICT (NRF-2016R1A2B4015623).

Ji-Yong Jung is with the Division of Biomedical Engineering, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, Republic of Korea (e-mail: cholbun@hanmail.net).

Chang-Min Yang is with the Department of Healthcare Engineering, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, Republic of Korea (e-mail: didckdals10@gmail.com).

Jung-Ja Kim is with the Division of Biomedical Engineering and Research Center of Healthcare & Welfare Instrument for the Aged, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, Republic of Korea (corresponding author to provide phone: 82-63-270-4102; fax: 82-63-270-2247; e-mail: jungjakim@jbnu.ac.kr).

rehabilitation medicine [9], [10]. Especially, in-shoe plantar pressure measurement is suitable to characterize dynamic gait and balance pattern [11]. However, until now, plantar pressure distribution data have been rarely used to analyze the gait characteristic of elderly people with visual impairment.

The purpose of this study was to understand the walking strategy of elderly people with visual impairment by comparing the differences in the plantar pressure parameters between walking without and with the white cane.

II. Methods

A. Subjects

10 male subjects with visual impairment (mean age: 62.6±12.1 years, mean height: 168.6±4.2 cm, and mean weight: 66.7±7.1 kg) participated in this study. All subjects were recruited from the Korea Blind Union in Jeonju, Republic of Korea. None of subjects had foot deformities, gait abnormality, or history of injury in the musculoskeletal system of the lower extremities. Before the experiment, all participants were provided written informed consent and informed about the purpose and clinical procedure of this study.

B. Measurement Instrument

The plantar pressure distribution measurement was conducted with the Pedar-X system (Novel GmbH, Munich, Germany), as shown in Fig. 1. Each insole contains 99 capacitive sensors with a thickness of 1.9 mm and a range of 15 – 600 kPa. These sensors are calibrated individually with the aid of the trublu calibration device (Novel GmbH, Munich, Germany). All data were transmitted to the Pedar-X software via Bluetooth wireless telemetry system in a wide range, at a sampling rate of 100 Hz.

C. Experimental Procedure

To assess the gait characteristics of elderly people with visual impairment, experimental procedure was divided into two conditions: walking without the white cane and with the white cane, as shown in Fig. 2. The Pedar-X system was attached to the waist of subjects using belt. The left and right cable was placed on each hand side for connecting the insoles. And then, both insoles was placed within the subject's shoes. To maintain the insole cable in place, the Velcro straps was used around the subject's limbs. And then, all subjects were instructed to walk at a comfortable speed along a 10 m walkway. Especially, both walking without and with the white cane conditions, the assistant also walked together behind the subject for safety. Before the experiment, subjects walked for 5 minutes for warm up and relaxation of the body. To prevent fatigue, subjects took a 5 minute rest in between experiments.

D. Data Analysis

Gait cycle is generally classified by the stance phase (60%) and swing phase (40%). In this study, the plantar pressure distribution of the left and right side during stand phase were analyzed by using Novel Pedar-X system software (Novel GmbH, Munich, Germany). As shown in Fig. 3, the foot surface

Fig. 1. Pedar-X system

Fig. 2. Experimental procedure
(a) walking without the white cane condition, (b) walking with the white cane condition

was divided into six regions: whole foot (foot length 0 – 100 %), forefoot (foot length 60 – 100 %), midfoot (foot length 30 – 60 %), rearfoot (foot length 0 – 30 %), medial foot (foot width 0 – 50 %), and lateral foot region (foot width 50 – 100 %). The six regions were calculated for maximum force, peak pressure, and mean pressure. The plantar pressure distribution during stance phase of force and pressure data were divided into five stage: initial contact (0-2 %), loading response (0-10 %), mid-stance (10-30 %), terminal stance (30-50 %), and pre- swing (50-60 %). Fig. 4 is presented the plantar pressure distribution during stance phase of the right foot.

III. Results

The maximum force, peak pressure, and mean pressure in the six regions of the foot when walking without and with the white cane as measured through plantar pressure distribution is compared in Table 1. The maximum force in the whole foot, medial and lateral foot region of the right foot side more increased significantly when walking with the white cane than walking without the white cane ($p < 0.05$). Differences in the maximum force between left and right side during walking under two conditions were showed similar patterns. The maximum force in the whole foot, forefoot, midfoot, rearfoot,

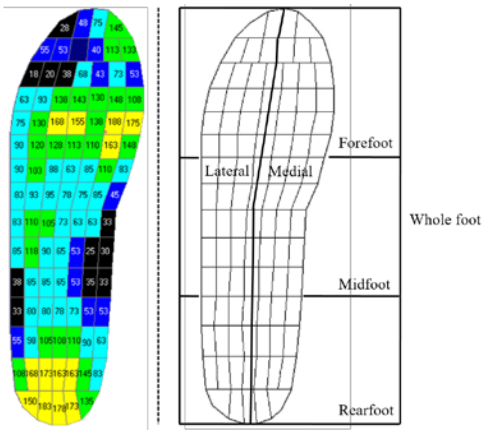

Fig. 3. Insole masks

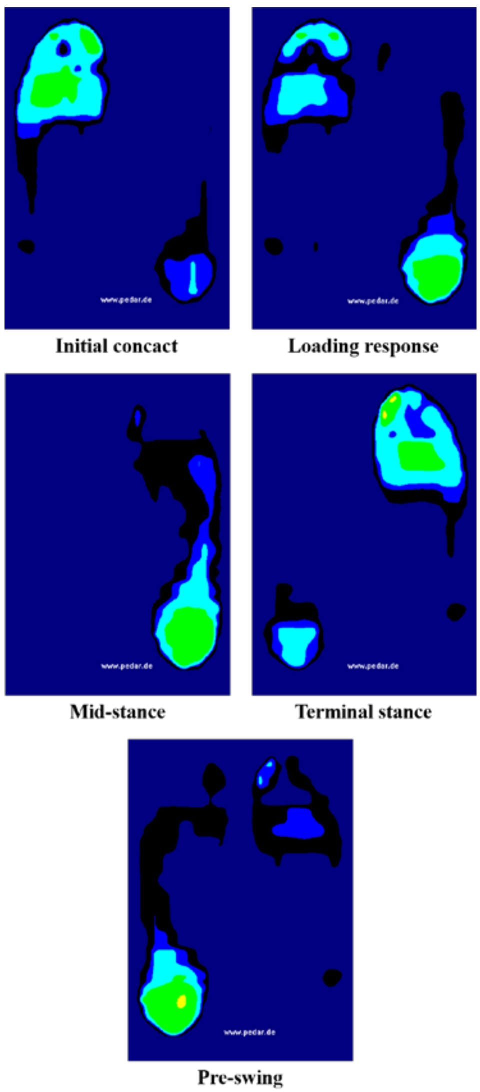

Fig. 4. The plantar pressure distribution during stance phase of the right foot

and lateral foot region of the right side were higher than the left side when walking without and with the white cane. However, in the midfoot region, there was only significant difference in the maximum force between left and right side ($p < 0.05$). The peak pressure in the whole foot, forefoot, and medial foot region increased significantly when walking with the white cane ($p < 0.05$). Contrary to the results in the maximum force, in walking without the white cane condition, increased peak pressures of the left side were shown in all regions except only the lateral foot region. In addition, in the whole foot, forefoot, midfoot, and medial foot region, significant difference in the peak pressure between left and right side was only presented ($p < 0.05$). Differences in the peak pressure patterns between left and right side when walking with the white cane were presented similarly in all regions except the midfoot and lateral foot region. Differences in the mean pressure between left and right side during walking under two conditions were showed similar patterns. In walking without the white cane condition, the mean pressure in all regions except the medial and lateral foot region of the right side were higher than the left side while different pattern was only shown in the medial foot region when walking with the white cane. But, in the midfoot region, there was only significant difference in the mean pressure between left and right side ($p < 0.05$). As compared with the mean pressure between when walking without and with the white cane, significant differences in the mean pressure were presented in the whole foot, medial foot, and lateral foot region ($p < 0.05$).

The force, peak pressure, and mean pressure during stance phase is presented in Fig. 5. The force at all stages except pre-swing of the right side were higher than the left side when walking without the white cane. On the other hand, in walking with the white cane condition, the force at terminal and pre-swing of the left side more increased than the right side. At initial contact, there was only significant difference in the force between left and right side ($p < 0.05$). When comparing two conditions, significant differences in the force were shown both at mid-stance and terminal stance ($p < 0.05$). The peak pressures at initial contact and loading response of the right side increased while that in the other stage of the same side decreased on both walking without and with the white cane conditions. There were significant differences in the peak pressure between left and right side at terminal and pre-swing when walking without the white cane ($p < 0.05$). However, significant difference was only presented at terminal stance when walking with the white cane ($p < 0.05$). As compared with the peak pressure between when walking without and with the white cane, significant differences in the peak pressure were shown at terminal stance and pre-swing ($p < 0.05$). The mean pressure at all stages except the pre-swing of the right side were higher than the left side when walking without and with the white cane. There was only significant difference in the mean pressure between left and right side at initial contact ($p < 0.05$). At terminal stance, significant difference in the mean pressure was only presented when comparing walking without and with the white cane conditions ($p < 0.05$).

IV. Discussion

The aim of the present study was to determine the differences in the plantar pressure distribution between walking without and

Table 1. Differences in plantar pressure in the six regions between when walking without and with the white cane

			Left	Right	p-value			Left	Right	p-value
Maximum Force (N)	Whole foot	Walking without the white cane	617.27 ±39.36	629.05 ±46.09	0.592	Fore foot	Walking without the white cane	533.13 ±49.72	532.18 ±41.99	0.969
		Walking with the white cane	622.31 ±44.96	642.82 ±45.30	0.334		Walking with the white cane	519.79 ±51.42	525.78 ±41.95	0.797
		p-value	0.529	0.017*			p-value	0.256	0.241	
	Mid foot	Walking without the white cane	190.91 ±12.55	212.13 ±16.66	0.004*	Rear foot	Walking without the white cane	451.24 ±49.06	467.81 ±50.42	0.455
		Walking with the white cane	191.68 ±13.37	215.99 ±13.49	0.002*		Walking with the white cane	449.84 ±44.51	471.15 ±57.88	0.313
		p-value	0.880	0.420			p-value	0.886	0.792	
	Medial foot	Walking without the white cane	356.23 ±32.07	326.79 ±24.33	0.555	Lateral foot	Walking without the white cane	473.83 ±25.95	482.69 ±39.14	0.602
		Walking with the white cane	357.13 ±37.76	344.56 ±20.78	0.448		Walking with the white cane	472.53 ±31.45	496.32 ±25.62	0.100
		p-value	0.914	0.012*			p-value	0.883	0.046*	
Peak Pressure (kPa)	Whole foot	Walking without the white cane	375.00 ±30.80	277.50 ±31.42	0.003*	Fore foot	Walking without the white cane	358.50 ±32.10	274.17 ±32.72	0.004*
		Walking with the white cane	373.75 ±52.49	312.92 ±43.29	0.190		Walking with the white cane	373.75 ±55.25	312.92 ±44.67	0.147
		p-value	0.500	0.021*			p-value	0.682	0.024*	
	Mid foot	Walking without the white cane	147.92 ±12.68	135.42 ±8.40	0.047*	Rear foot	Walking without the white cane	226.25 ±23.37	207.92 ±24.13	0.895
		Walking with the white cane	143.33 ±13.60	153.75 ±21.58	0.137		Walking with the white cane	257.92 ±27.35	229.17 ±24.35	0.965
		p-value	0.420	0.460			p-value	0.686	0.467	
	Medial foot	Walking without the white cane	375.00 ±32.23	268.33 ±32.74	0.002*	Lateral foot	Walking without the white cane	236.67 ±22.04	268.75 ±21.62	0.405
		Walking with the white cane	373.75 ±54.32	306.25 ±45.66	0.116		Walking with the white cane	251.25 ±19.87	278.75 ±21.10	0.083
		p-value	0.545	0.048*			p-value	0.690	0.388	
Mean Pressure (kPa)	Whole foot	Walking without the white cane	39.92 ±2.97	40.54 ±2.79	0.581	Fore foot	Walking without the white cane	90.23 ±7.03	94.04 ±8.03	0.969
		Walking with the white cane	41.48 ±2.92	42.31 ±2.81	0.334		Walking with the white cane	88.56 ±6.90	92.96 ±8.01	0.797
		p-value	0.504	0.017*			p-value	0.256	0.241	
	Mid foot	Walking without the white cane	38.47 ±2.82	39.74 ±2.16	0.004*	Rear foot	Walking without the white cane	103.25 ±12.17	107.77 ±12.53	0.455
		Walking with the white cane	35.89 ±2.83	42.51 ±2.25	0.002*		Walking with the white cane	115.82 ±14.25	116.73 ±13.53	0.725
		p-value	0.880	0.419			p-value	0.886	0.600	
	Medial foot	Walking without the white cane	60.79 ±3.55	51.90 ±3.72	0.056	Lateral foot	Walking without the white cane	55.25 ±4.44	54.84 ±3.43	0.602
		Walking with the white cane	60.93 ±3.25	56.36 ±3.46	0.502		Walking with the white cane	55.71 ±2.69	56.93 ±3.46	0.100
		p-value	0.914	0.002*			p-value	0.883	0.046*	

(Mean±SD), *$p < 0.05$

with the white cane for understanding gait characteristic of elderly people with visual impaired.

In general, the visually impaired person hold the white cane with one hand and swing it from side to side with pressure of the wrist and fingers for detecting and avoiding obstacles. The motion of the cane can effect on the gait mechanism of individuals with a visual impairment [12]. Accordingly, use of the white cane continuously during walking could be connected directly the change of gait pattern. As compared the maximum force and mean pressure between when walking without and

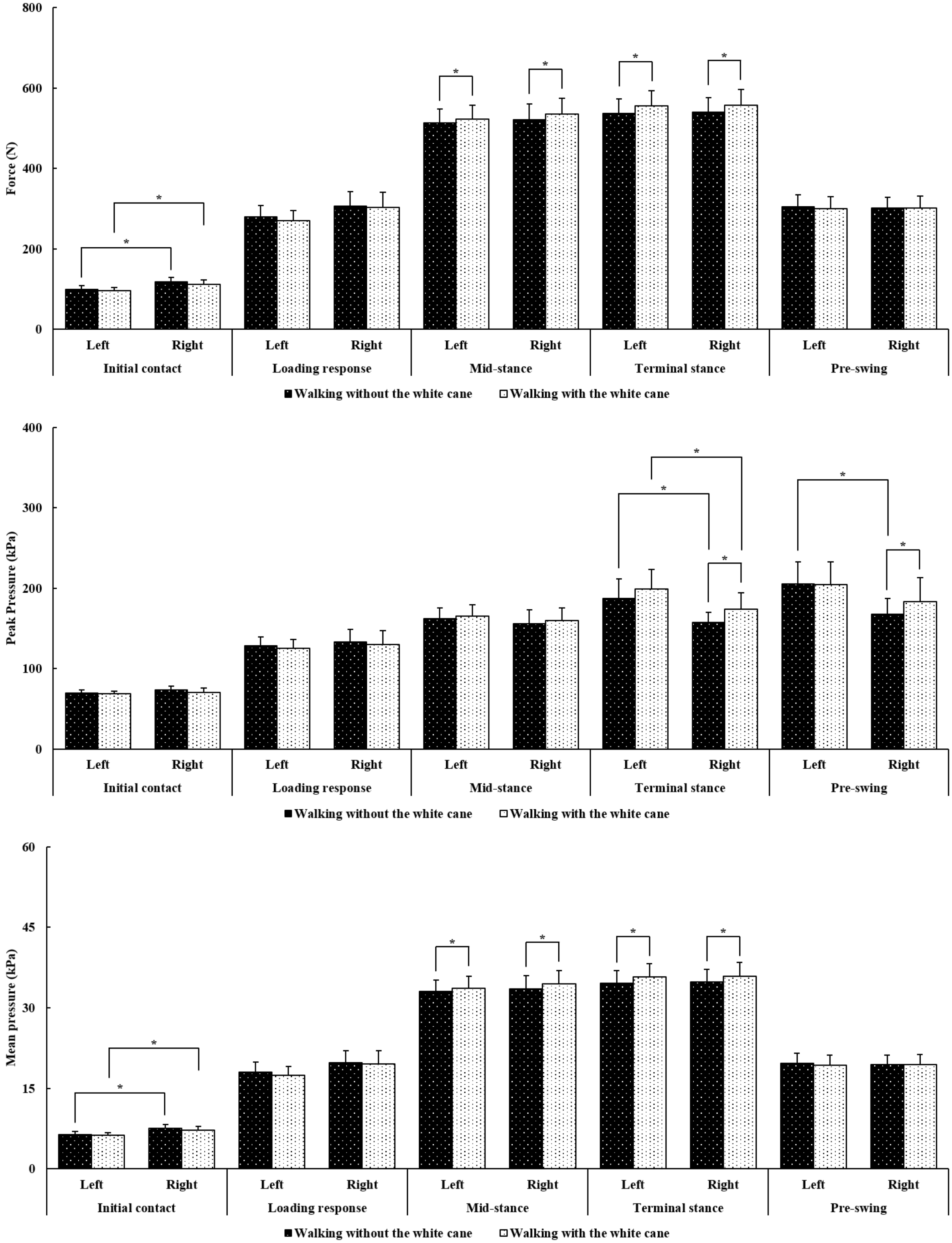

Fig. 4. Differences in plantar pressure during stance phase between when walking without and with the white cane

with the white cane, the pressure distributions were changed similarly. In walking with the white cane condition, the maximum force and mean pressure in the whole foot, medial and lateral foot region of the right side increased significantly. Increased maximum force and mean pressure in the medial and lateral foot region of the right side affect the whole foot region, and it may be associated with body sway caused by using the white cane. In addition, the force and pressure at mid-stance and terminal stance was higher significantly when walking with the white cane than walking without the white cane. It seems that the white cane may have influence on cautious walking pattern with increased strength, stride, contact time, and gait velocity of the right foot. This result is consistent with the previous research which also reported that individuals with visual impairment showed shorter stride length, earlier foot contact, and careful gait strategy to keep a postural stability [13].

The plantar pressure distribution including the maximum force, peak pressure, and mean pressure in the medial foot region of the left side increased while these parameters in the lateral foot region decreased. Especially, significant difference in the force and pressure was only shown at initial contact. Commonly, elderly people with visual impairment used the white cane on the right side. With continuous movement of that side for detection obstacle, asymmetrical balance patterns of users were presented. This gait imbalance was also observed that the maximum force and mean pressure of the right side increased while the peak pressure of the left side increased during walking. In previous researches demonstrated that visually impaired person had poorer body balance in the anterioposterior and mediolateral directions during both static and dynamic conditions [14-16]. From these results, we confirmed that asymmetrical pressure distribution pattern can be induced by holding and swing the white cane to the front side with only one hand during walking, and it also can affect the postural balance continuously when walking without the white cane.

The peak pressure in the forefoot and medial foot region of the right side increased significantly when walking with the white cane. And, there were also significant increase in the peak pressure during the terminal stance and pre-swing phase. Consequently, the significant differences in the peak pressure values between left and right side more decreased when walking with the white cane than walking without the white cane. From the results, we confirmed that significant increase in the plantar pressure distribution in the terminal stance and pre-swing phase can be directly linked to the peak pressure in the forefoot, midfoot, and medial foot region. Generally, the white cane have been designed primarily to provide physical stability to a visually impaired person when walking. Reduced peak pressure between left and right side during walking with the white cane is very meaningful result which suggest positive effect of the white cane on improvement of posture and balance stabilization [17]. However, conventional white cane has some limitations such as including lack of range for obstacle detection at different heights and distances, and continuous use of the white cane may can cause discomfort during walking that is associated with gait dysfunction as well as postural imbalance of elderly people with visual impairment. Early intervention to enhance the postural balance of elderly people with visual impairment for preventing risk of injury and falls may be important [7]. Accordingly, with regard to develop the new types of walking assistive device, it is necessary to consider the gait characteristic and dynamic postural balance pattern.

V. Conclusion

The main objective of this study was to investigate the plantar pressure distribution of elderly people with visual impairment based on the foot regions and gait cycle. In the current study, increased plantar pressure distributions of the right side including the maximum force and mean pressure between walking without and with the white cane were founded while the opposite tendency between two conditions was presented in the peak pressure. Postural balance of elderly people with visual impairment can be influenced positively by the walking assistive device. Furthermore, in-shoe pressure measurement can be utilized to analyze the gait mechanism and postural stability pattern of people who are visually impaired. The finding of this study suggest that understanding of the gait characteristic may have important factor for improving physical activity in daily life and proving the efficient rehabilitation methods to adapt in unfamiliar environments for elderly people with visual impairment. Thus, further study will be conducted to develop the new types of walking assistive device based on the results of this study.

Acknowledgment

This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1A6A3A119 34555) and the Ministry of Science and ICT (NRF-2016R1A2B 4015623).

References

[1] B. G. Manoj, and V. Rohini, “A novel approach to object detection and distance measurement for visually impaired people,” Int J Comput Intel Res, vol. 13, no. 4, pp. 479-484, 2017.

[2] Y. Wang, and K. J. Kuchenbecker, “HALO: haptic alerts for low-hanging obstacles in white cane navigation,” in 2012 IEEE Haptics Symposium (HAPTICS), 2012, pp. 527-532.

[3] S. Pundlik, H. Yi, R. Liu, E. Peli, and G. Luo, “Magnifying smartphone screen using google glass for low-vision users,” in IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2016, pp. 1-10.

[4] A. Adebiyi, P. Sorrentino, S. Bohlool, C. Zhang, M. Arditti, G. Goodrich, and J. D. Weiland, “Assessment of feedback modalities for wearable visual aids in blind mobility,” PLoS One, vol. 12, no, 2, pp. 1-17.

[5] Y. Niitsu, T. Taniguchi, and K. Kawashima, “Detection and notification of dangerous obstacles and places for visually impaired persons using a smart cane,” in 2014 7th International Conference on Mobile Computing and Ubiquitous Networking (ICMU), 2014, pp. 68-69.

[6] World Health Organization. Action plan for the prevention of avoidable blindness and visual impairment, 2014-2019 [Online]. Available: https://www.who.int/blindness/AP2014_19_English.pdf.

[7] H. K. Lee, and R. J. Scudds, “Comparison of balance in older people with and without visual impairment,” Age Ageing, vol. 32, no. 6, pp. 643-649, 2003.

[8] Z. O. Abu-Faraj, E. Jabbour, P. Ibrahim, and A. Ghaoui, "Design and development of a prototype rehabilitative shoes and spectacles for the blind," Proceedings of the 5th International Conference on BioMedical Engineering and Informatics, 2012, pp. 683-687.
[9] K. Imaizumi, Y. Iwakami, K. Yamashita, and Y. Hiejima, "Development of an evaluation system for foot arch types in the elderly using foot pressure distribution data," in 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2012, pp. 4859-4862.
[10] J. A. Ramirez-Bautista, J. A. Huerta-Ruelas, S. L. Chaparro-Cárdenas, and A. Hernández-Zavala, "A review in detection and monitoring gait disorders using in-shoe plantar measurement systems," in 2017 IEEE Reviews in Biomedical Engineering, 2017, pp. 1-1.
[11] Z. O. Abu-Faraj, Y. T. Faraj, K. H. Mohtar, and M. M. Rammal, "Characterization of plantar pressures in visually impaired individuals: A pilot study," in 2013 6th International IEEE/EMBS Conference on Neural Engineering (NER), 2013, pp. 1549-1553.
[12] J. T. Johnson, B. F. Johnson, B. B. Blasch, and W. D. de I´Aune, "Gait and long cane kinematics: a comparison of sighted and visually impaired subjects," J Orthop Sports Phys Ther, vol. 27, no. 2, pp. 162-166, 1998.
[13] A. Hallemans, E. Ortibus, F. Meire, and P. Aerts, "Low vision affects dynamic stability of gait," Gait Posture, vol. 32, no. 4, pp. 547-551, 2010..
[14] R. A. Ozdemir, A. Pourmoghaddam, and W. H. Paloski, "Sensorimotor posture control in the blind: superior ankle proprioceptive acuity does not compensate for vision loss," Gait Posture, vol. 38, no. 4, pp. 603-608, 2013.
[15] V. Sobry, P. Badin, S. Cernaianu, O. Agnani, and M. Toussaint, "Do visually impaired people have a static balance as effective as sighted people?," NeuroRehabilitation, vol. 35, no. 4, pp. 851-861, 2014.
[16] P. Giagazoglou, I. G. Amiridis, A. Zafeiridis, M. Thimara, V. Kouvelioti, and E. Kellis, "Static balance control and lower limb strength in blind and sighted women," Eur J Appl Physiol, vol. 107, no. 5, pp. 571-579, 2009.
[17] R. B. Parreira, L. A. C. Grecco, and C. S. Oliveira, "Postural control in blind individuals: a systematic reviw," Gait Posture, vol. 57, pp. 161-167, 2017.

Ji-Yong Jung He received the B. S., M. S., and Ph. D. degree from the Chonbuk National University, Jeonju, Republic of Korea, in 2010, 2012, and 2016, respectively. He is currently a research assistant professor at Chonbuk National University. His major research interest is the postural balance, gait analysis, wearable devices for the visually impaired, and rehabilitation.

Chang-Min Yang He received the B. S. degree from the Chonbuk National University Jeonju, Republic of Korea, in 2016. His major research interest is the wearable devices for the visually impaired, gait analysis, and functional shoes.

Jung-Ja Kim She received the B. S., M. S., and Ph. D. degree from the Chonbuk National University , Gwangju, Republic of Korea, in 1985, 1988, 2002, respectively. She worked with electronic telecommunication Laboratory at Chonnam National University from 2002 to 2004, and Korea Bio-IT Foundry Center at Gwangju from 2004 to 2006. She is currently a professor at Chonbuk National University. Her major research interest is the big data analysis (bio and medical data analysis), artificial intelligence, and rehabilitation.