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Development and Evaluation of Shoe-type Walking Assistive Device for Visually Impaired Person

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Generally, the walking assistive device for a visually impaired person is the white cane. The white cane has many problems such as collision and gait imbalance when walking with it. In addition, it is difficult to prepare for falls because the hand holding of the white cane is not free. Therefore, in this study, we developed a shoe-type walking assistive device. The device was equipped with infrared distance sensors, pressure sensors, and vibrating motors in shoes. The infrared sensor detects the distance between obstacles and the shoes. The pressure sensor is attached to detect the heel strike during the gait cycle. The vibration motor changes the intensity of its vibration according to changes in the distance between the shoes and obstacles. To evaluate the effectiveness of the developed shoe-type walking assistive device, we compared the required time, number of collisions, and electromyogram (EMG) of the lower limbs of 11 visually impaired persons while walking with the white cane. The results showed that there was no significant difference in the number of collisions between the white cane and the shoe-type walking assistive device and that the required time of the shoe-type walking assistive device was larger than that of the white cane. In addition, the difference in EMG between the lower limbs when using the shoe-type walking assistive device was smaller than that when using the white cane. Therefore, the developed shoe-type walking assistive device for visually impaired people provides a lower walking velocity than the white cane. However, it can detect obstacles to a similar extent and reduce the imbalance of the user.

1. Introduction

The number of individuals with visual impairment worldwide is increasing every year. Commonly, many visually impaired people use a white cane from among the various walking assistive devices available, owing to its simplicity, low cost, and portability.[1] The white cane

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is a symbol of blindness and independence as well as the most basic tool for the blind to achieve mobility. A visually impaired person can move quickly and safely using the white cane, which is held with one hand and swung forward, backward, and to both sides of the user to detect and avoid obstacles.

However, the range for detecting obstacles close to the ground during walking is limited.[2,3] Owing to this limitation, visually impaired people who use a white cane are at risk of repeated falls, injury, and body imbalance.[4] Although some visually impaired people use guide dogs to solve these problems, guide dogs require a lot of time for special training and money for food and medical expenses.[5]

In recent years, new types of walking aids with improved functionality such as smart clothes with intelligent canes and electronic devices have been developed, through the dramatic advances of wearable computing and IT for visually impaired people.[6–9] These walking assistive devices can be categorized as electronic travel aids (ETAs) and robotic travel aids (RTAs), including smart canes, red green blue-depth (RGB-D) cameras, Google glass, smartphone-based wearable systems, motor wheelchair systems, and wearable portable systems.[6] However, previous walking assistive devices for the visually impaired are focused only on improving obstacle detection accuracy without considering appearance and cost.[10–12] Additionally, biomechanical changes that may be induced by walking assistive devices should be considered. However, despite the importance of the evaluation of the effect of the developed devices on the biomechanical characteristics of visually impaired subjects during walking, it has been little studied until now.

In this paper, we manufactured a new shoe-type walking assistive device equipped with infrared distance sensors, vibrating motors, and pressure sensors. To evaluate the effects of this device on the gait of a visually impaired person, comparative analyses of the required time, number of collisions, and lower limb muscle activity during walking with a white cane and a shoe-type walking assistive device under different conditions were performed.

2. Methods

2.1 Subjects

Eleven visually impaired subjects participated in this study. The mean age, height, and body weight of the subjects were 62.3 ± 5.5 years, 169.0 ± 2.0 cm, and 66.4 ± 3.2 kg, respectively. Three people with abnormal gait were excluded. Before the experiment, all subjects gave written informed consent prior to their participation.

2.2 Configuration of the device

The developed shoe-type walking assistive device consists of conventional shoes, infrared distance sensors, vibrating motors, and pressure sensors. The infrared distance sensors (GP2Y0A02YK0F, Sharp, Japan) with a detection range of 20–150 cm, were attached on the front and side upper portions of the shoes. These sensors were connected to the vibrating motor to provide accurate information about the direction and distance of obstacles. The dimensions of the sensor were 44.5 × 18.9 × 21.6 mm^3 with a weight of about 5 g. To provide the information about the gait cycle, flexible pressure sensors (A201-25, Tekscan, USA), with a detection range of 0–25 Ib, were attached in the rear of both insoles. The dimensions of the pressure sensors were 197 × 14 × 0.127 mm^3, and the pressure was measured in a circle with a diameter of 9.53 mm at the end of the sensor. A disc-type jig was designed thinly and manufactured using a 3D printer (Clon S270, K.CLONE, Republic of Korea) not only to improve the accuracy of signal detection but also to fix the pressure sensor with the minimum stimulation during walking. As shown in Fig. 1, all signals of the shoe-type walking assistive device were transmitted to the data acquisition (DAQ) board (National Instrument Corp, Texas, USA), which was attached to the back of the pants with a clip.

To assess the required time and number of collisions, an analysis program was developed using LabVIEW 2010 software (National Instrument Corp., Texas, USA). The obstacle detection distances were determined 60 cm maximally as the average maximum distance of subjects with a white cane. The infrared distance sensor detected obstacles continuously during walking, and vibrating motors were operated with increasing vibrational intensity gradually from 60 to 0 cm. The vibrating motors were deactivated in the toe-off phase because the infrared distance sensor on the upper side was headed for the ground in that phase. Vibration intensity was classified into three levels as follows: no vibration (without 60 cm), weak vibration (within 60–30 cm), and strong vibration (within 30–0 cm), as shown in Fig. 2.

2.3 Experimental setup

The experiment was carried out in a small box area (7.5 m in length and 3 m in width) with obstacles that were 15 ± 3 cm in length, 17 ± 3 cm in width, and 20 ± 5 cm in height. The obstacles were arranged in 5 rows such as 3, 4, 3, 4, and 3. All subjects were instructed to walk along the corridor under two conditions: walking with the white cane and walking with the shoe-type walking assistive device (Fig. 3). The experiment procedure was repeated three

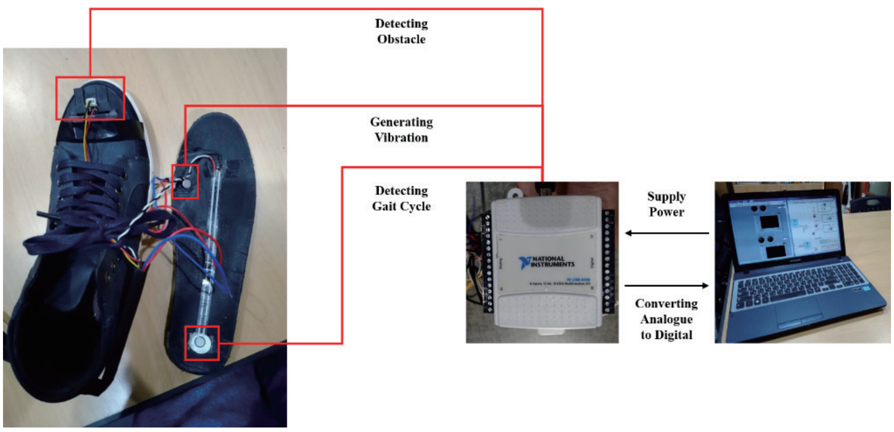

Fig. 1. (Color online) Developed shoe-type walking assistive device.

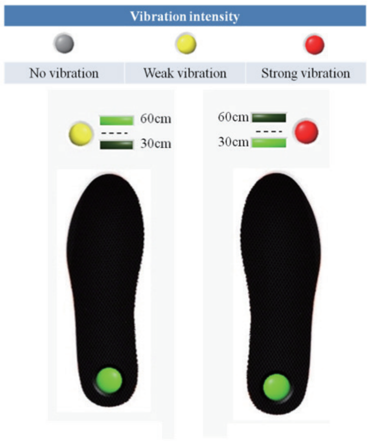

Fig. 2. (Color online) Obstacle detection program.

(a) (b)

Fig. 3. (Color online) (a) Walking with the white cane and (b) walking with the shoe-type walking assistive device.

times to assess the required time and number of collisions during walking. To evaluate the biomechanical aspect of the shoe-type walking assistive device, lower limb muscle activity was measured using the Noraxson Desktop DTS System (Noraxson Inc., Scottsdale, USA). Surface electrodes were attached to the eight lower limb muscles on both sides, including the tibialis anterior, vastus lateralis, biceps femoris, and vastus lateralis muscles. Before placing electrodes in the corresponding area, the skin was shaved and cleaned with alcohol to remove the skin resistance. The electromyogram (EMG) data was rectified, smoothened, and bandpass filtered (passband 20–450 Hz). Then, the raw data were averaged by using root mean square (RMS) to acquire the average amplitude of the EMG signal.

2.4 Statistical analysis

Statistical analysis was performed using SPSS 12.0 (IBM Corp., Chicago, USA). Normality Shapiro–Wilk test was conducted for the normality of all variables. Differences in muscle activity between the left and right sides were compared by the Wilcoxon signed-rank test. The differences in the required time and number of collisions between walking with the white cane and with the shoe-type walking assistive device were analyzed through the Mann–Whitney U test. The level of significance was $p < 0.05$.

3. Results

3.1 Required time and number of collisions

Table 1 shows the results of the required time and number of collisions. When using the shoe-type walking assistive device, the required time was significantly higher (about 85.7%) than that using the white cane ($p = 0.013$). The required time between the first and third tests decreased by 6.8 and 7.4% when walking with the white cane and with the shoe-type walking

Table 1
Required time and number of collisions.

Required time(s)			
	White cane	Shoe-type walking assistive device	p-value
1st	26.98 ± 3.97	51.96 ± 8.48	0.013*
2nd	29.25 ± 3.54	50.57 ± 8.28	0.012*
3rd	25.14 ± 3.37	48.14 ± 5.73	0.012*

Number of collisions			
1st	1.75 ± 0.64	1.00 ± 0.27	0.131
2nd	2.25 ± 0.58	1.38 ± 0.46	0.408
3rd	1.63 ± 0.65	1.13 ± 0.42	0.196

($M \pm SD$) $*p < 0.05$

assistive device, respectively. However, there was a significant difference in the required time only when walking with the white cane (p = 0.028). The number of collisions with the shoe-type walking assistive device decreased by about 37.4% compared with that with the white cane. The number of collisions between the first and third tests decreased by 6.9% when walking with the white cane while it increased by 13.0% when walking with the shoe-type walking assistive device. In contrast, there were no significant differences in the number of collisions between the two conditions.

3.2 EMG

All muscle activities except vastus lateralis muscles were higher when walking with the white cane than with the shoe-type walking assistive device. When walking with the white cane, the differences in muscle activities between the left and right sides were 9.7% in the tibialis anterior muscle, 1.7% in the vastus lateralis muscle, 18.1% in the biceps femoris muscle, and 17.9% in the lateral gastrocnemius muscle. When walking with the shoe-type walking assistive device, differences in muscle activities between both sides were 5.8% in the tibialis anterior muscle, 9.9% in the vastus lateralis muscle, 1.2% in the biceps femoris muscle, and 0.9% in the lateral gastrocnemius muscle (Fig. 4). Large differences in the muscle activities between the left and right sides were shown in the biceps femoris and lateral gastrocnemius muscles when walking with the white cane. These differences were greatly reduced when walking with the shoe-type walking assistive device. However, there was a significant difference in the biceps femoris muscle between the left and right sides only when walking with the white cane.

4. Discussion

In this paper, we developed the shoe-type walking assistive device equipped with infrared distance sensors, vibrating motors, and pressure sensors for visually impaired people. To evaluate the effectiveness of this device, the required time, number of collisions, and limb muscle activity on both sides when walking with a white cane and with a shoe-type walking assistive device were compared.

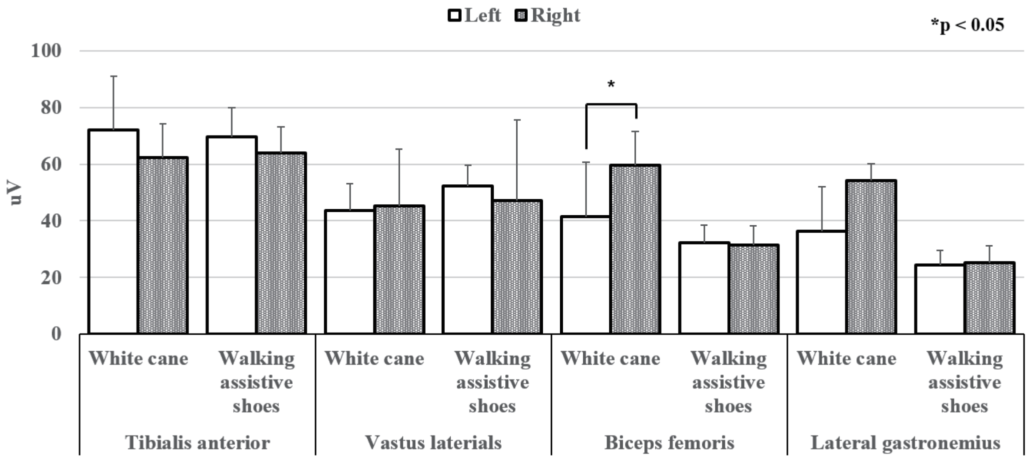

Fig. 4. Differences in muscle activities between left and right sides when walking with the white cane and shoe-type walking assistive device.

The results showed that the number of collisions decreased while the required time increased significantly when walking with the shoe-type walking assistive device. Collisions with obstacles are more dangerous for visually impaired people than for ordinary people because they may cause falls, injuries, and body imbalance. Therefore, the decreased number of collisions when walking with the shoe-type walking assistive device is the meaningful result that can help prevent some problems during walking. In contrast, the required time was significantly higher when walking with the shoe-type walking assistive device. Generally, the white cane can be used to detect obstacles in a short time through intuitive contact while the shoe-type walking assistive device needs a relatively long time to provide information about the obstacles identified by sensor signals.[(13)] Accordingly, the results of this study showed that the overall required time was shorter for the white cane than for the shoe-type walking assistive device in the small box area. However, the decrease in the required time over three trials was larger when walking with the shoe-type walking assistive device than with the white cane. Thus, time is necessary to adapt to the new shoe-type walking assistive device, and the required time would be decreased if a user had time to adapt to the shoe-type walking assistive device.

Comparison ofthe muscle activation patterns shows that the differences in averaged muscle activities between the left and right sides were 11.85% for the white cane and 4.45% for the shoe-type walking assistive device. Particularly, for the white cane, there were large differences in biceps femoris and lateral gastrocnemius muscle activities between the left and right sides. In general, postural stability in the elderly with impaired vision could be reduced and most visually impaired people hold a white cane with only one hand to detect obstacles during walking. Accordingly, long-term walking with a white cane may cause lower limb muscle imbalance, fatigue, and an abnormal gait pattern.[(14,15)] From the results, we confirmed that the shoe-type walking assistive device can help improve the lower extremity muscle imbalance.

5. Conclusions

In this study, we developed a shoe-type walking assistive device with infrared distance sensors, vibrating motors, and pressure sensors for the visually impaired to detect obstacles and improve the lower limb muscle imbalance during walking. When walking with the shoe-type walking assistive device, the required time increased while the number of collisions decreased. In addition, the differences in muscle activities of the lower extremity between the left and right sides were largely reduced when walking with the shoe-type walking assistive device. From the results of this study, we concluded that the new shoe-type walking assistive device can improve the gait of the visually impaired person by the quick adaptation of device as well as improved satisfaction by decreasing the number of collisions during walking. This suggests that the shoe-type walking assistive device will be a typical walking assistive device in the future by solving problems such as convenience, appearance, functionality, and usability for visually impaired people.

However, this study has several limitations. The experiment was conducted only in a small box area without actual external environments such as stairs or slopes. Therefore, further studies will be conducted to improve technical defects in various actual external environments.

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