

# Laser-light Visual Cueing Shoes with Foot Pressures and Inertial Sensing for Individuals with Parkinson's Disease\*

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**Abstract**— Gait disorder is a core problem in individuals with Parkinson's disease (PD), including bradykinesia, shuffling steps, festinating gait, and freeze of gait (FOG). Laser-light visual cueing has been demonstrated to be efficient in the mediation of gaits and the reduction in number of FOG episodes. However, previous approaches commonly adopted independent controls of visual cueing on left and right sides which was prone to produce two cues while individual was not in normal walking. In this study, we developed laser-light visual shoes which produced interlaced visual cues for left and right feet in a manner of one-side cueing at a time, solving the aforementioned problem. With parallel measurement of foot inertial data and foot pressures in each shoe, our results showed that the proposed visual cueing made PD individuals in the on-medication condition walk with a longer stance and swing times, that is, they walked more carefully and stable. The proposed approach can also be used to study kinematic and kinetic characteristics of gaits in the off-medication condition to clarify the mediation of visual cueing on motor control of PD individuals.

**Clinical Relevance**— This demonstrates the effect of laser-light visual cueing on gaits in individuals with Parkinson's disease.

## I. INTRODUCTION

Gait disorder is a core problem in individuals with Parkinson's disease (PD), including bradykinesia, shuffling steps, festinating gait, and freeze of gait (FOG), which is prone to cause postural instability, thereby increasing risk of falls. Placement of visual targets such as transverse lines, inverted sticks, etc. along the walkway gives a visual cueing, which has been demonstrated to be efficient in gait improvement and reductions in number and time of FOG episodes in PD individuals [1]. Lee *et al.* showed that visual cueing by placing stripes along walkway significantly increased stride length, step length, and velocity as well as reductions in cadence, time to complete a trial, and number of FOG episodes in PD individuals who were diagnosed to have a FOG symptom, whereas visual cueing resulted in decreases in velocity and

cadence and an increase in time to complete a trial in PD individuals without FOG diagnosed [2].

However, placing visual targets along walkway has a limitation in real-life application that it is only available in a specific environment. Equipment with a laser light device on a cane or an assisted walker solves this problem [3]. The projected cueing line gives PD individual an immediate guidance to step over in any available place. Alternatively, placing a laser light device on each foot was used to project two distinct laser beams interlacedly for contralateral foot to step over [4, 5].

The effect of laser visual cueing for PD individuals has been investigated in several studies. Donovan *et al.* demonstrated the efficacy of using a cane or walker with laser-light cues in a month could overcome FOG, evidenced by the reductions in FOG questionnaire scores and fall frequency compared to the 1-2 month baseline period of use of the same assisted device but without visual cues [3]. Kompoliti *et al.* demonstrated a significant correlation between the time to complete a gait trial and number of FOG episodes while using a laser visual beam stick [6]. Barthel *et al.* demonstrated that visual cueing using laser-light shoes significantly reduced number of FOG episodes and the percent frozen time but no significant changes in gait measures in PD individuals [7]. However, Bunting-Perry *et al.* found no significant differences in time to complete tasks, number of steps, and number of FOG episodes between walk conditions aided by a rolling walker with and without laser visual cueing [8].

The aforementioned studies have demonstrated the efficacy or effect of laser-light visual cueing via a cane, a walker, or shoes. Implementation of laser-light visual cueing device on shoes has a benefit of producing distinct cueing lines for left- and right-side stepping. Nevertheless, control of laser-light activation works independently on each side, thereby visual cueing from left and right sides may be activated at the same time, particularly in situation while individual is not in normal walking, e.g. bradykinesia, shuffling steps, festinating gait, and FOG. In this study, we developed laser-light visual cueing shoes which was equipped with eleven force sensitive

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resistors (FSRs) in the insole to measure foot pressures, and an inertial measurement unit (IMU) with an accelerometer, a gyroscope, and a magnetometer. The inertial data and foot pressures on both feet were wireless transmitted to a smart phone for storage and real-time processing for controlling laser-light cueing so that only one-side cueing is activated at a time. The measured inertial data and foot pressures were used to investigate the effect of laser-light cueing on the adaptations of gait and center of plantar pressures (COP).

## II. METHODS

### A. Laser-light Visual-Cueing Shoes

We developed laser-light visual shoes to produce cueing line on the floor and collect foot inertial data and foot pressures in parallel. Each shoe was equipped with a laser-light emitter device on the top cap and a sensing and control device at the lateral side. As shown in Fig. 1, an IMU (LSM9DS1, STMicroelectronics, Geneva, Switzerland) with a full-scale, ranged  $\pm 4$  g tri-axial accelerometer, a full-scale, ranged  $\pm 500$  degrees/sec tri-axial gyroscope, and a full-scale, ranged  $\pm 12$  Gauss tri-axial magnetometer) was used to measure inertial data. A customized insole with eleven FSRs (UNEO Incorporated, New Taipei City, Taiwan) was used to capture foot pressures at the big toe, little toe, metatarsus (medial, middle, lateral), arches (medial, lateral), fore heels (medial, lateral), and heels (medial, lateral). The FSRs were constructed of a resistance-type piezo-resistive polymer composite made using processing and printing-based micromachining technology. Each FSR had a sensing range of 1 to 5 Kg/cm<sup>2</sup> and was individually calibrated using elastic-film pressurization to reduce the resistance variance between the sensors. The customized insole had a height of 260 mm, a metatarsus width of 850 mm, a heel width of 550 mm, and a 0.63 mm thickness [9].

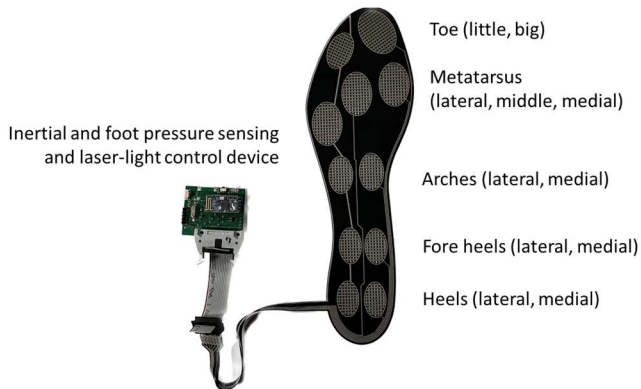


Figure 1. An inertial and foot pressure sensing and laser-light control device for measuring foot pressures at eleven areas and controlling a laser-light cue.

An ARM Cortex-M4 microcontroller (M451RG6AE, Nuvoton Tech. Corp., Hsinchu, Taiwan) received digital data from an IMU via a serial peripheral interface bus at a sampling rate of 100 Hz and digitized the transformed voltages from eleven FSRs through a built-in 12-bit analog-to-digital converter at a sampling rate of 100 Hz. All of the acquired samples were wirelessly transmitted to a smart phone through a BLE 4.2 Bluetooth module (JDY-18, Shenzhen Innovation Technology, Shenzhen, China).

The foot pressures in left foot were detected to turn on laser-light cueing for right foot to step over, as shown in Fig. 2(a). Similarly, laser light on right foot was activated to produce a cueing line for left foot, as shown in Fig. 2(b).

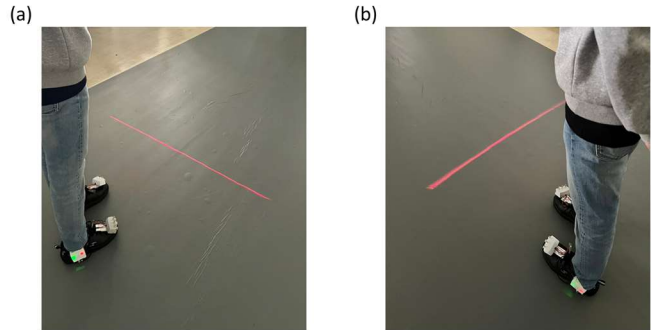


Figure 2. Laser-light visual cueing for individual with Parkinson's disease.

### B. Subjects and Gait Experiment

Ten PD individuals participated gait experiments. They took their dopaminergic medications about 2 hours before the experiment so that they were in the on-medication condition for walking with an affordable motor control. Each participant performed walking forth and back over 7 meters twice. Every gait task was performed by each of the participants under two conditions with and without visual cueing whose order was counterbalanced across participants. The protocol of this study was approved by the Research Ethics Committee of the Chang Gung Medical Foundation (IRB#201900664B0) in accordance with the Helsinki Declaration. All participants gave written informed consent.

### C. Gait Parameters and Center of Pressures

We used three parameters to measure gait characteristics: (1) stance time defined as the time from heel-strike to toe-off; (2) swing time defined as the time from toe-off to heel-strike; (3) double support time defined as the time that both feet were contacted on the ground.

COP was calculated from eleven individual foot pressures:  $fp_1(i), fp_2(i), \dots, fp_{11}(i)$ . COP<sub>x</sub> and COP<sub>y</sub> of each foot are, respectively, defined as the sum of the products of the eleven individual foot pressures and their x and y positions divided by the sum of the eleven foot pressures:

$$COP_x(i) = \frac{\sum (fp_n(i) * x_n)}{\sum fp_n(i)} \quad (1)$$

$$COP_y(i) = \frac{\sum (fp_n(i) * y_n)}{\sum fp_n(i)} \quad (2)$$

where  $x_n$  and  $y_n$  indicate the location of the of the centroid of the  $n$ -th FSR relative to the local reference frame. Based on the COP trajectory on each foot, we calculated length of COP trajectory during stance time (from heel-strike to toe-off, as shown in Fig. 3) and COP speed defined as the COP length divided by the stance time.

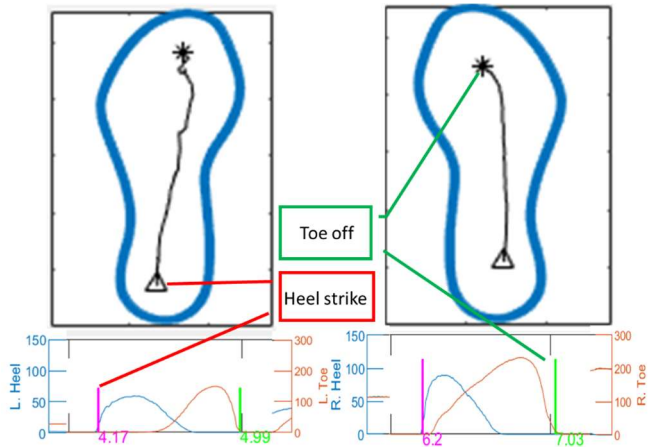


Figure 3. Center of plantar pressure trajectories during the stance times of left and right feet.

### III. RESULTS

Table I lists the results of gait parameters while PD individuals walking forth and back with and without laser-light cueing. Visual cueing significantly reduced stance time, single support time, and swing time in both affected and unaffected sides.

TABLE I. GAIT PARAMETERS WHILE PD INDIVIDUALS WALKING WITH AND WITHOUT LASER-LIGHT CUEING

	Off-cueing	On-cueing	<i>p</i> value
Affected side			
Stance time, s	0.945 ± 0.161	1.227 ± 0.223	0.003
Single support time, s	0.531 ± 0.080	0.628 ± 0.130	0.021
Swing time, s	0.526 ± 0.057	0.645 ± 0.097	0.012
Unaffected side			
Stance time, s	0.940 ± 0.141	1.228 ± 0.223	0.003
Single support time, s	0.523 ± 0.057	0.637 ± 0.096	0.010
Swing time, s	0.531 ± 0.072	0.639 ± 0.126	0.026
Double support time, s	0.365 ± 0.093	0.527 ± 0.173	0.003

All data are presented as mean ± standard deviation. The paired *t* test was used to compare differences between walks with off-cueing and on-cueing. *p* < 0.05 is regarded to be significantly different.

Table II lists the results of COP parameters while PD individuals walking forth and back with and without laser-light cueing. Visual cueing significantly increased COP length during stance time in both affected and unaffected sides but decreased COP speed during stance time in the unaffected side.

TABLE II. COP PARAMETERS WHILE PD INDIVIDUALS WALKING WITH AND WITHOUT LASER-LIGHT CUEING

	Off-cueing	On-cueing	<i>p</i> value
Affected side			
COP length, cm	21.15 ± 3.75	26.90 ± 5.81	0.003
COP speed, cm/s	23.42 ± 5.78	22.85 ± 4.68	0.631
Unaffected side			
COP length, cm	24.90 ± 3.29	29.82 ± 4.32	0.001
COP speed, cm/s	27.49 ± 4.61	24.99 ± 4.26	0.012

All center of pressures (COP) data are presented as mean ± standard deviation. The paired *t* test was used to compare differences between walks with off-cueing and on-cueing. *p* < 0.05 is regarded to be significantly different.

### IV. DISCUSSION

In this study, PD individuals were recruited for gait trials in the on-medication condition. Our results showed that visual cueing made individuals walk with a longer stance and swing times, that is, they walked more carefully and stable. In previous studies, application of laser-light visual cueing in PD individuals with on-medication had a reduction effect in number of FOG episodes as well as under off-medication [7] but no effect on gait measures were shown as well as another study [8]. PD individuals in the on-medication condition have benefits of maintenance of motor control, particularly in situation of daily-life walking but other non-medication factors like environment triggers and cognitive inputs caused unpredictable gait disturbances [10], affecting the assessment of efficacy of visual cueing. Future study on PD individuals in the off-medication condition will be beneficial to clarify the effect of the proposed laser-light visual cueing on gaits in another aspect.

Interlacing presentation of left and right-side cueing works well in normal walking. However, gait disorders, such as shuffling steps, festinating gait, and FOG commonly break the interlacing because left- and right-side laser-light controls work independently in previous approaches. The proposed one-side visual cueing at a time can avoid the confounding when two cueing lines are simultaneously presented by comparing the COPs of left and right feet. Further investigation is needed to refine the algorithm for one-side visual cueing at a time for aforementioned gait disorders.

The gait assessments in previous approaches need additional measurement devices such as IMU and electronic walkway. The proposed laser-light visual cueing system simultaneously measures foot inertial data and foot pressures of both feet for kinematic and kinetic analyses, which is beneficial to study the mediation of motor control while visual cueing is applied.

### V. CONCLUSION

We developed laser-light visual shoes to produce interlaced visual cues on the floor for left and right feet with a parallel measurement of foot inertial data and foot pressures. In particular, the proposed visual cueing operates in a manner of one-side cueing at a time, thereby solving the confounding caused by simultaneous presentation of two cueing lines which commonly occurs in gait disorders. Our results showed that the proposed visual cueing made PD individuals in the on-medication condition walk with a longer stance and swing times, that is, they walked more carefully and stable. Further study involving kinematic and kinetic analyses in the off-medication condition can help clarify the mediation of visual cueing on motor control of PD individuals while having affected walking states.

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