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Original Article

The effects of visual cues from optical stimulation devices on gait disturbance in patients with Parkinson's disease

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Abstract. [Purpose] The purpose of this study was to identify the optimal visual cues for gait disturbance in patients with Parkinson's disease based on the luminous duration and the individual patient preferences for a wearable visual cue device. [Participants and Methods] Twenty-four patients with Parkinson's disease walked while wearing only a visual cue device in the control condition. They then walked while the device was set to two stimulus conditions: the luminous duration at 10% and 50% of the individual gait cycle. After walking under the two stimulus conditions, the patients were asked for their preferred visual cue condition. The walking results were compared between the two stimulus conditions and the control condition. Gait parameters were compared among the three conditions. The comparisons with preference, non-preference, and control conditions were also made for the same gait parameter. [Results] When compared to the control condition, walking with visual cues in the stimulus conditions reduced stride duration and increased cadence. The preference and non-preference conditions had shorter stride durations than the control condition. Furthermore, the preference condition also resulted in a faster gait speed than the non-preference condition. [Conclusion] This study suggests that a wearable visual cue device with the patient's preferred luminous duration may help manage gait disturbance in patients with Parkinson's disease.
Key words: Parkinson's disease, Visual cue, Gait disturbance

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INTRODUCTION

Parkinson's disease (PD) is associated with many motor symptoms[1, 2)]. Patients with PD commonly experience gait disturbances such as small shuffling steps, an anteriorly shifted center of mass, decreased walking speed, poor balance, increased gait variability, and freezing of gait (FOG) as the disease progresses[3)]. FOG is a unique and disabling clinical phenomenon characterized by brief episodes of inability to step or by extremely short steps that typically occur on initiating gait or on turning while walking. And FOG is released via sensory cues[4)].

Based on previous studies, cueing is an intervention method using external visual, auditory, and somatosensory stimuli to improve gait disturbance in patients with PD[5, 6)]. For example, cues can be accomplished by using tape attached to the floor for visual stimulation, a metronome for auditory stimulation, and a vibration device for somatosensory stimulation. Rocha et al., Spaulding et al., and Lim et al. reported in systematic reviews that cues, such as visual, auditory, and somatosensory stimuli, improved gait disturbance in PD, but they could not determine which type of cues were most appropriate for patients with PD[7–9)]. Specifically, several studies have reported on the effect of cueing on the gait disturbances of patients with PD.

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Recent studies support the idea that cueing can be an effective component of locomotor therapy for patients with PD and gait disturbance, that auditory cueing is most effective for influencing the temporal parameters of gait only, and that visual cueing has been used to improve the spatial parameters[10, 11] and reduce step/stride length variability and asymmetry[11]. Focusing on the effects of cueing on FOG in patients with PD, Lee et al. compared the effects of visual and auditory cues on patients with PD who were experiencing FOG, and found that visual cues reduced FOG increased stride length and gait speed, and improved lower extremity joint movements during walking[12].

However, the authors highlighted that the benefits of cueing may be limited because laboratory studies have very controlled research settings and, thus, the results are not generalizable to overground locomotion in the community[11]. The authors further recommended the development of wearable systems that could be used at home or in the community to improve gait disturbance in patients with PD[11]. Ginis et al. noted that novel cueing systems, such as wearable devices, for the improvement of gait disturbance among patients with PD have been developed in recent years, but further investigations are required to establish which modality is the most effective in different circumstances[13]. Moreover, Beck et al. and Sweeney et al. indicated that patients with PD improved in gait when their FOGs were relieved by visual cues[14, 15]. We concur that visual cueing may be useful for improving gait in patients with PD, and thus, we focused on the effect of wearable visual cues. New mobile technologies, such as smart glasses, can deliver visual cues, and these may improve gait disturbance in patients with PD in their natural environment[16]. Nieuwboer et al., Zhao et al., and Ferrarin et al. have reported on a "spectacle-type" device that uses light-emitting diodes (LED) as the visual cue, and the effects on gait characteristics were positive[16, 17]. Nieuwboer et al. used a device that produced a flash of light, generated by a LED, that was attached to the patient's spectacles or a pair of clear glasses, and found that cueing increased the speeds of turn in all patients with PD[17]. Zhao et al. evaluated rhythmic visual cueing in the laboratory setting with a custom-made application for Google-Glass, and found that more stable gait patterns emerged during cueing, particularly on complicated walking courses, but that FOG did not significantly decrease in patients with PD[16]. In addition, Ferrarin et al. reported that the use of a portable device with optical stimulation modalities resulted in an increase in gait speed and cadence in patients with PD[18].

While these reports have indicated that visual cueing using a portable visual stimulation device may improve gait disturbance in patients with PD, they have not clarified the specific conditions of the visual cues, such as the color and intensity of the light or its luminous duration. Therefore, as a preliminary study, we created a set of optical-stimulating goggles with programmable LED lights that provided cues in the peripheral visual field (Optical Gait Assist System: OGAS, Takei Scientific Instruments Co., Ltd., Niigata, Japan) and explored the color (blue or white) and intensity (weak, medium, or strong) of the visual cues to determine the OGAS parameters that improved gait disturbance in patients with PD. According to the results, most patients preferred the color blue and moderate intensity. Then, the effects of visual cues were further refined by investigating different luminous ratios (10%, 30%, or 50% of the gait cycle in each patient). The gait parameters changed significantly according to different visual cue conditions. The greatest change was noted at a luminous ratio of 10% and 50%.

However, at the 10% or 50% luminous ratio of the gait cycle as visual cues, the relationship between the patient's preferred stimulus conditions and the actual effect on the different gait parameters was not clear. Hence, the purpose of this study was to clarify the desired conditions for improving gait disturbance in patients with PD using visual cues based on the relationship between luminous ratio at 10% or 50% of the gait cycle and individual patient's preferences or non-preferences while using the optical-stimulating goggles with programmable LED lights that provide cues in the peripheral visual field.

PARTICIPANTS AND METHODS

Twenty-four patients with PD (10 females and 14 males), aged 70.2 ± 7.2 years (mean ± SD), with a mean height of 161.0 ± 12.2 cm, and a mean body weight of 57.0 ± 10.8 kg, were included in this study. Patients included both inpatients and outpatients from the National Hospital Organization Matsumoto Medical Center who volunteered to participate in the study from November 2021 to November 2022 (Table 1). Inclusion criteria included: a diagnosis of idiopathic PD; stable medication usage; Hoehn and Yahr stages I, II, or III; the ability to walk independently; and being aged 20 years or older. Patients were excluded if they had undergone functional neurosurgery; showed cognitive impairment; had disorders interfering with participation in cueing sessions, including neurological, cardiopulmonary, and orthopedic conditions; or had unpredictable and long-lasting off periods. Basic data, including age, height, weight, and foot length, were obtained. Disease severity was determined using Hoehn and Yahr staging. The study was approved by the Ethics Committee of Shinshu University School of Medicine (No. 4981). All patients understood the procedure and purpose of the study, and they provided written informed consent before participation.

This is a cross-sectional study. Before measurements, basic data and the Freezing of Gait Questionnaire were obtained from the participants. First, the participants were instructed to walk 10 meters down the hallway wearing the OGAS without visual cues as a control condition. In this control condition, the stride duration was measured using small inertial measurement units worn on both feet (RehaGait®, HASOMED GmbH, Magdeburg, Germany), and the LED lights' flashing duration was set to a luminous ratio of 10% or 50% of the individual gait cycle. Next, the participants walked 10 meters down the hallway in the same way as in the control condition, but this time with the visual cues turned on. The trial was repeated for two stimulus conditions: the luminous ratio at 10% (LR10%) and 50% (LR50%). To reduce bias from fatigue, the order of the two conditions was randomly assigned. Furthermore, patients rested for one minute between each condition.

Gait characteristics, such as gait speed, cadence, stride length, and duration were measured in participants for each of the three conditions using RehaGait®. The OGAS was equipped with LED lights on the frames of the goggles, and these could be adjusted for a position in the peripheral vision. The type of visual stimulus (optical stimulus duration) can also be freely changed using a program on the personal computer (Fig. 1). A questionnaire was administered after walking *in situ* to collect information on each participant's impression of their walkability and whether they preferred the OGAS setting of LR10% or LR50%.

Descriptive statistics were used to analyze the mean and the coefficients of variation (CV) of the stride length and duration, mean of gait speed, and cadence, and the two types of three conditions were compared: the control, LR10%, and LR50% conditions, and the control, preference (Pref), and non-preference (N-Pref) conditions. The normality of the obtained data was then checked using the Kolmogorov-Smirnov test. Since normality was found for comparisons among the control, LR10%, and LR50% conditions in terms of the mean of stride duration, stride length, gait speed, and cadence, the repeated-measures analysis of variance (ANOVA) was conducted as a parametric test, while the Friedman test was performed for the CV of stride duration and stride length since normality was not found. In addition, the same statistical analyses were performed for the same parameters in relation to the control, Pref, and N-Pref conditions. Since normality was found for comparisons in terms of the means of stride duration, gait speed, and cadence, the repeated-measures ANOVA was conducted as a parametric test, while the Friedman test was performed for the mean of stride length, the CV of stride duration and stride length since normality was not found for. Post-hoc tests for each analysis were performed using the Bonferroni's method. Statistical analyses were conducted using SPSS 28.0 for Windows (SPSS Inc., Chicago, IL, USA), with a statistical significance level of 5%.

RESULTS

Table 2 shows the results of comparing the control, LR10%, and LR50% conditions in relation to gait characteristics. There was a significant main effect of the mean and CV of the stride duration (mean: $F(2, 46)=13.105$, $p<0.001$, $\eta^2=0.364$, CV: $p=0.002$). Significant differences in the mean and CV of the stride duration between LR10% and the control condition (mean: $p=0.004$, CV: $p=0.007$) and between LR50% and the control condition (mean: $p<0.001$, CV: $p=0.007$) were also

Table 1. Participant characteristics

Participants	24
Age (years, range)	70.2 ± 7.2 (52–81)
Gender (males/females)	(14/10)
Height (cm, range)	161.0 ± 12.2 (140.0–184.0)
Weight (kg, range)	57.0 ± 10.8 (40–83)
Disease duration (years, range)	5.3 ± 3.4 (14.0–0.3)
Hohen & Yahr staging	2.4 ± 0.6
FOGQ	10.2 ± 6.0
Preference condition (10%/50%)	(13/11)

Data are mean ± SD.
FOGQ: Freezing of Gait Questionnaire; SD: standard deviation.

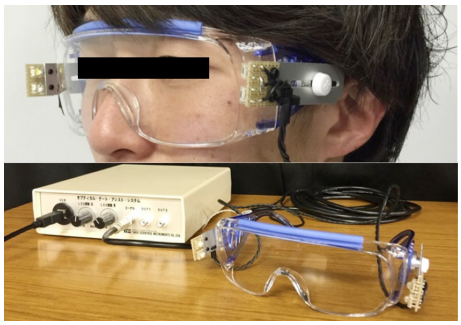

Fig. 1. Optical Gait Assist System (OGAS) Takei Scientific Instruments Co., Ltd., Japan.
The optical-stimulating goggles with programmable LED lights indicate cues in the peripheral visual field on the left and right sides. The color and intensity of the light can be adjusted with a control box, and the duration of the light can be adjusted via an application on a personal computer.

observed in the post-hoc test. Conversely, there were no significant differences among the control, LR10%, and LR50% conditions for the mean and CV of the stride length (mean: $F(2, 46)=0.052$, $p=0.949$, $\eta^2=0.004$, CV: $p=0.167$). For the mean gait speed, the results also showed no significant differences ($F(2, 46)=1.299$, $p=0.283$, $\eta^2=0.055$). While there was a significant main effect in the mean of the cadence ($F(2, 46)=13.336$, $p<0.001$, $\eta^2=0.367$), the significant differences in the mean of the cadence between LR10% and the control condition ($p=0.004$) and between LR50% and the control condition ($p<0.001$) were observed in the post-hoc tests.

Table 3 shows the results of comparing the control, Pref, and N-Pref conditions in relation to the gait characteristics. There was a significant main effect of the mean and CV of the stride duration (mean: $F(2, 46)=15.313$, $p<0.001$, $\eta^2=0.400$, CV: $p=0.001$). Significant differences in the mean and CV of the stride duration between the Pref and control conditions (mean: $p<0.001$, CV: $p=0.042$), and between the N-Pref and control conditions (mean: $p=0.005$ CV: $p=0.001$) were observed in the post-hoc tests. There were no significant differences among the control, Pref, and N-Pref conditions for any stride lengths (mean: $p=0.130$, CV: $p=0.197$). For the mean gait speed, there was a significant main effect ($F(2, 46)=3.379$, $p=0.043$, $\eta^2=0.128$). A significant difference in the mean gait speed between the Pref and N-Pref conditions ($p=0.044$) was also observed in the post-hoc test. There was a significant main effect on the mean cadence ($F(2, 46)=15.224$, $p<0.001$, $\eta^2=0.398$). Significant differences in the mean cadence between Pref and the control condition ($p<0.001$), and between N-Pref and the control condition ($p=0.006$), were observed in the post-hoc tests.

Table 2. Comparison of the gait parameter in the control, LR10%, and LR50% conditions

	Control	LR10%	LR50%	Control vs. LR10%	Control vs. LR50%	LR10% vs. LR50%
Stride duration						
mean [s]	1.15 ± 0.14	1.09 ± 0.12	1.11 ± 0.14	**	***	
CV	0.061 ± 0.022	0.042 ± 0.013	0.044 ± 0.017	**	**	
Stride length						
mean [m/s]	0.89 ± 0.25	0.90 ± 0.24	0.89 ± 0.24			
CV	0.081 ± 0.067	0.086 ± 0.038	0.076 ± 0.041			
Speed						
mean [m/s]	0.80 ± 0.24	0.83 ± 0.26	0.83 ± 0.25			
Cadence						
mean [step/min]	105.9 ± 12.3	110.3 ± 13.2	110.7 ± 13.1	**	***	

Data are mean ± SD.
Statistically significant, *p<0.05, **p<0.01, ***p<0.001.
LR10%: luminous ratio at 10% of the gait cycle; LR50%: luminous ratio at 50% of the gait cycle; CV: the coefficient of variation; SD: standard deviation.

Table 3. Comparison of the gait parameter in the control, Pref, and N-Pref conditions

	Control	Pref	N-Pref	Control vs. Pref	Control vs. N-Pref	Pref vs. N-Pref
Stride Duration						
mean [s]	1.15 ± 0.14	1.09 ± 0.12	1.11 ± 0.14	***	**	
CV	0.061 ± 0.022	0.043 ± 0.017	0.042 ± 0.013	*	**	
Stride Length						
mean [m/s]	0.89 ± 0.24	0.91 ± 0.23	0.88 ± 0.24			
CV	0.081 ± 0.067	0.076 ± 0.034	0.086 ± 0.044			
Speed						
mean [m/s]	0.80 ± 0.24	0.85 ± 0.24	0.81 ± 0.26			*
Cadence						
mean [step/min]	105.9 ± 12.3	111.3 ± 12.8	109.7 ± 13.5	***	**	

Data are mean ± SD.
Statistically significant, *p<0.05, **p<0.01, ***p<0.001.
Pref: participant preferred conditions; N-Pref: conditions that the patient did not prefer; CV: the coefficient of variation; SD: standard deviation.

DISCUSSION

The purpose of this study was to clarify the desired conditions of the visual cues for gait disturbance improvement in patients with PD based on the relationship between two types of luminous duration and the preference conditions while using the optical-stimulating goggles with visual cues.

The results showed that the visual cue conditions (LR10% and LR50%, and Pref and N-Pref) had the effects of reducing the mean and CV of the stride duration and increasing the mean cadence relative to the control condition. Moreover, when comparing the Pref and N-Pref conditions, Pref was more effective in increasing the gait speed than N-Pref. These findings suggest that both types of conditions for the visual cues of the wearable device (LR10% and LR50%, and Pref and N-Pref) improved the temporal parameters of gait characteristics more than in the control condition. Furthermore, gait speed with the Pref condition was faster than the N-Pref condition.

It has been reported that the gait characteristics of patients with PD include a narrower stride length and FOG and that when the gait speed is varied, the cadence is adjusted instead of the stride length, which leads to gait disturbance as it is difficult to adjust[19]. In contrast, cueing can be an effective component for improving the gait disturbance of patients with PD as the visual cues can increase spatial parameters, and reduce stride length variability[11]. In this study, we found that the use of visual cues shortened the stride duration, reduced stride duration variability, and increased the cadence compared to the control condition. Few reports on visual cues have experimented with changes in the stride duration, one of the temporal parameters. Furthermore, the effect of the visual cues on the stride duration was reported as the cycle time by Janssen et al[20]. They used smart glasses to show bars and stairs in augmented reality and compared them to the traditional visual cues of horizontal bars, reporting that the cycle time was longer for the horizontal bars, although the variability was not significantly different between conditions. Changes in stride duration using visual cues have also been reported. To date, there has been no report on the stride duration with visual cues using rhythmic light stimuli, such as OGAS. Meanwhile, there were several reports on auditory cues that are affected by temporal parameters. In a meta-analysis of rhythmic auditory stimulation (RAS), Ghai et al.[21] reported that the double limb support phase, which is part of stride duration, was longer when using RAS, while a meta-analysis by Ye et al.[22] reported no difference in stride duration, and the authors concluded that the effect of RAS on stride duration remained unclear. Unlike conventional visual cues, such as using horizontal bars on the floor, or innovative visual cues using augmented reality, our findings suggest that the visual cues based on rhythmic timing for the presentation of light stimuli influenced the temporal rather than spatial parameters, such as the mean and CV of the stride duration.

When comparing the different test conditions, LR10% and LR50%, to the control condition, significant differences were found in the mean stride duration, which increased in the order of LR10%, LR50%, and the control condition, whereas no significant differences were found in the gait speed. Conversely, when comparing the control, Pref, and N-Pref conditions, significant differences were found in both the mean stride duration and the gait speed. The stride duration increased in the order of Pref, N-Pref, and the control condition. For the gait speed, it decreased in the order of Pref, N-Pref, and the control condition. Moreover, the Pref condition was associated with a significantly faster gait speed than the N-Pref condition. Then, significant differences were also observed in the CV of the stride duration, which is an index of regularity in gait, when comparing the control condition with LR10% and LR50%. Furthermore, the LR10% and LR50% conditions demonstrated a significantly decreased CV of the stride duration compared to the control condition. Meanwhile, when comparing the control, Pref, and N-Pref conditions for the CV of the stride duration, significant differences were found among the three conditions, with the Pref and N-Pref conditions being associated with a significantly decreased CV of the stride duration compared to the control condition. These results indicated that the light stimulus conditions may increase the regularity of gait more than the control condition using either LR10% or LR50%, and Pref or N-Pref conditions. However, it is useful to use the light stimuli of the Pref condition that the individual patient found comfortable when walking, and thus, in this study, the Pref condition may be considered the desired visual cue for improving gait speed.

When comparing the LR10% and LR50% conditions, no significant differences in the gait characteristics were found. However, these two stimulus conditions were more effective in improving stride duration and cadence than the control condition. Our results suggest that the rhythmic light stimulus itself may affect the improvement of gait disturbance in patients with PD rather than the duration of the luminous ratio, such as 10% or 50% of the gait cycle. Furthermore, the light stimulus conditions that the patient felt most comfortable walking with could induce an increase in gait speed compared to the non-preferred condition. These results also demonstrated that rhythmic visual stimulation increased regularity in the stride duration among patients with PD. Based on this study, the visual cues preferred by an individual patient may be the most useful for increasing the gait speed and step-by-step regularity (stride duration) of patients with PD.

This study has some limitations. First, the effectiveness of OGAS on FOG is not clear, as we did not observe significant FOG in the participants of this study. Furthermore, since detailed cognitive functions were not investigated, it was not known how cognitive functions affected the selection of preferred conditions by the participants. In future studies, the recruitment criteria should be revised to ensure that the effect of OGAS on FOG can be further investigated. Second, because this study was conducted in an experimental setting, it is not possible to discuss its usefulness in a home-like setting. Also, to collect measurements for this experiment, the wearable visual cue equipment was connected by wires, and a measurer must be present. Hence, the effectiveness of wearable equipment in daily life could not be determined. Further research and development

of the device are needed to clarify its effectiveness in the daily lives of patients. Additional research studies to determine the different and/or better ways of using the device, so that it can be used in the clinical rehabilitation setting for PD patients, are warranted.

In conclusion, our findings suggest that the use of wearable visual cues may be effective in improving gait disturbance in patients with PD. Furthermore, setting the conditions of the visual stimulation according to the preferences of the patients may speed up their gait. In the future, it is anticipated that the development of wearable devices that enable the customization of patient preferences and needs will lead to clinical applications for use in daily life and as a physical therapy training method.

Conference presentation

Our preliminary research, "Suitable visual cues for gait disturbance in patients with Parkinson's disease: an exploratory study", was presented at the Asian Confederation for Physical Therapy Congress 2018 on Lahug, Cebu City, Philippines, November 23–25, 2018, and the number of the abstract in poster sessions was 56.

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Conflicts of interest

There is no conflict of interest.

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