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The effect of visual cues on muscular activation in the lower limbs of Parkinson's disease patients with freezing of gait: a preliminary study*

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Abstract— **Freezing of gait (FOG) is a disabling symptom of Parkinson's disease (PD) patients, especially in advanced stages. Visual cues, such as the laser, have been confirmed to improve kinematic performance and alleviate FOG incidences. However, the muscular effect is unknown. In this study, we aim to investigate the effect of visual cues on muscular activity in the lower limbs of PD patients with FOG. Surface EMG signals of the tibialis anterior (TA), lateral gastrocnemius (GL), rectus femoris (RF), and biceps femoris (BF) muscles were collected from eight patients (FOGer) and eight healthy elderly (HC) in both normal walking and walking with laser cues. Results showed that visual cues improved FOGer's muscular activation pattern towards normal. The RMS of TA was significantly increased in the loading response phase (p=0.02) and decreased in the pre-swing phase for FOGer (p=0.005) under visual cue. The RMS of GL in FOGer was considerably reduced in the loading response phase (p<0.001) and increased in the pre-swing phase (p=0.008) of their gait cycle. A significant strong correlation was also observed between the decrement in GL RMS during the loading response phase and the increment in GL RMS during the pre-swing phase (R=-0.952, p<0.001) incurred by visual cue in FOGer. These results indicate that the visual cues can help FOGer to modulate their muscular activation of ankle muscles, especially to normalize GL's activation distribution during stance. For clinical purposes, future rehabilitative strategies aimed at the modulation of ankle muscles are suggested.**

I. Introduction

Freezing of gait (FOG), commonly defined as a brief, episodic absence or marked reduction of the feet's forward progression despite the intention to walk [1], is said to be the most debilitating gait disturbance in Parkinson's disease (PD). FOG dramatically increases the risk of fall for patients with PD and affects their quality of life.

Dopaminergic treatment is the most common clinical solution to overcome FOG. Unfortunately, as the disease progresses, the daily dosage can be a dangerous factor leading to levodopa-induced dyskinesia [2] and could also cause dopamine resistance in most patients [3]. Several physiotherapy techniques have been developed to alleviate the FOG [4], and the visual cues may be the best cue modality for lessening FOG [5]. Previous biomechanical studies reported that visual cues could improve the range of motion and moment of patients' lower joints during walking [6,7]. However, the neuromuscular mechanism behind its effectiveness is unclear. There are few papers focused on the effect of visual cues on muscular activation. Understanding the specific effect of visual cues on muscular activity under the alleviation of FOG can provide crucial theoretical guidance for this disease's rehabilitation.

This study aimed to investigate the effect of visual cues on muscular activation in the lower limbs of PD patients with FOG. We hypothesized that the alleviation of FOG under visual cues would be accompanied by the normalization of muscular activation patterns during different gait phases.

II. Methods

A. Subjects & Data collection

Eight PD patients with FOG (FOGer) and eight healthy elderly controls (HC) were recruited in the study. The age, sex, height, and weight of HC are matched with FOGer (age: HC *vs* FOGer=70.9±5.3 *vs* 71.8±5.5, p=0.636; sex(M/F): HC *vs* FOGer=6/2 *vs* 5/3, p=0.602; height(m): HC *vs* FOGer=1.66±0.07 *vs* 1.63±0.08, p=0.370; weight(kg): HC *vs* FOGer=69.36 ± 11.95 *vs* 64.96 ± 8.66, p=0.462). The experimental procedures were explained to the subjects, and they signed an informed consent form before doing the experiment. The study was approved by the Ethics Review Committee of Science Technology Research involving People, Shanghai Jiao Tong University (No: E20200035I).

Kinematic data during walking was collected by an eight-camera three-dimensional (3D) motion capture system (Vicon Nexus 1.8.5, Oxford Metrics, Oxford, UK) with a sampling frequency of 100 Hz. Four infrared-reflexive markers located on the second toe and heel of bilateral feet were used to calculate spatiotemporal parameters. Surface EMG signals of tibialis anterior (TA), lateral gastrocnemius (GL), rectus

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femoris (RF), and biceps femoris (BF) muscles in the left and right leg were collected at a sampling rate of 2000Hz, using eight wearable EMG sensors (Delsys, Boston, USA). The placement of the sensors was based on the SENIAM guidelines [8].

B. Experimental procedures

The experiments were conducted in the biomechanical laboratory of Shanghai Jiao Tong University, China. Each subject was asked to walk back and forth along a 10-meter long path at their preferred speed (Nolaser condition). Next, a wearable laser device that projected a laser line on the ground one step length before the subject's feet was attached over the sternum. During the visual cue condition, subjects were asked to step on the projected laser line during walking (Laser condition). Seven trials' walking data were collected for each condition. Each subject was asked to rest for about two minutes after two successive trials.

C. Data analysis

FOG episodes were defined as episodes existing longer than 1s, where the subject was unable to continue the ongoing walking [9]. The average number of FOG episodes during one 10-meter walk and the average duration of FOG episodes were also recorded to measure the effect of different conditions on FOG.

This study compared the kinematic and EMG data of the FOGer's more-affected side with the average of both legs in HC. Spatiotemporal parameters and EMG parameters were calculated in Matlab (R2019a, MathWorks, Natick, USA). Gait events of left and right legs during constant walking, including toe-off (TO) and heel-strike (HS), were identified by the vertical velocity curve of the midpoint between the heel and second toe marker, where TO and HS were the instant of peak and the second trough of the curve, respectively [10]. Cadence (steps/time), stride length(m), double stance time (% of the gait cycle) and speed (m/s) were calculated for each walk repetition.

Each EMG signal was filtered with a zero-lag fourth-order 20~500 Hz Butterworth band-pass filter. The EMG signal's envelope was calculated by the method of Root Mean square (RMS) with the window length of 250 ms and normalized to its mean value in the gait cycle [11]. To quantify the amount of activation in each muscle during the gait cycle, the RMS value of EMG envelope in the four different sub-phases of loading response phase (from ipsilateral HS to contralateral TO), single stance phase (from TO to HS in the contralateral leg), pre-swing phase (from contralateral HS to ipsilateral TO) and swing phase (from TO to the next HS in the ipsilateral leg) was calculated for each muscle respectively [12] (Fig. 2). The EMG envelope's peak value and its location with respect to the duration of the gait cycle were calculated for GL and BF. The peak value and peak location of TA and RF were respectively calculated in the stance and swing phase, as both muscles burst in the stance and swing phase separately.

D. Statistical analysis

The Shapiro-Wilk test was performed to test the normality of data. The Wilcoxon Signed Ranks Test was used to analyze those non-normal distribution parameters. For those normal distribution parameters, the effect of group and condition on each kinematic and EMG parameter were analyzed by two-factor repeated-measures analysis of variance (ANOVA) with post-hoc test. The Spearman correlation analysis was used to assess the relationship between the changes in kinematic performance and muscular activation under Laser and Nolaser conditions. All statistical analyses were performed in SPSS Release 22 (SPSS, Chicago, USA).

III. Results

All parameters were normally distributed except for FOG incidence in Laser condition ($p<0.01$) and FOG average duration($p=0.019$ in Nolaser condition, $p=0.001$ in Laser condition).

There were no main effects of group × condition interaction for all spatiotemporal parameters. Compared with HC, FOGer walked with a higher cadence ($p=0.693$), remarkably shorter stride length ($p<0.001$), longer double stance time ($p=0.003$), and slower speed ($p<0.001$) in Nolaser condition. Although laser cue didn't affect HC's kinematic performance (no statistical significance in any parameters between the two conditions), it changed FOGer kinematic parameters considerably. The average number of FOG was significantly reduced in FOGer after the laser cue was applied ($p=0.043$) (Fig. 1). The laser cue was also associated with significantly decreased cadence ($p=0.01$), increased stride length ($p=0.004$), shorter double stance time ($p=0.049$) and higher speed ($p=0.036$) in FOGer.

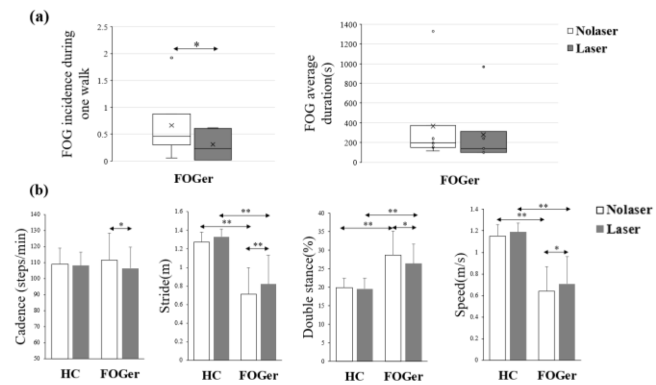

Figure 1. Incidence and duration of FOG in Nolaser and Laser condition for FOGer (a), spatiotemporal results of HC and FOGer in Nolaser and Laser condition (b). (*p<0.05, *p<0.01).

There were significant main effects of group × condition interaction in TA RMS of pre-swing phase ($p=0.019$) and GL RMS of loading response phase($p<0.01$). Compared with HC, FOGer showed a lower value of TA RMS in loading response phase ($p=0.069$) and significantly higher TA RMS in pre-swing phase ($p=0.029$) under Nolaser condition. And the value of GL RMS was remarkably higher ($p=0.004$) during loading response phase, significantly lower during single stance phase ($p=0.005$) and lower during pre-swing phase ($p=0.184$) in FOGer than HC under Nolaser condition (Fig. 2 & Fig. 3). When FOGer walked with laser cue, their TA RMS was significantly increased in the loading response phase ($p=0.02$) but significantly decreased in the pre-swing phase ($p=0.005$) and swing phase ($p=0.003$). The value of GL RMS was significantly decreased during loading response phase (p<0.01) and increased during the pre-swing phase (p<0.01) in FOGer under laser condition. There was no significant difference in RF RMS in FOGer between the two conditions. The BF RMS of FOGer was significantly increased in the pre-swing phase under laser condition (p=0.042).

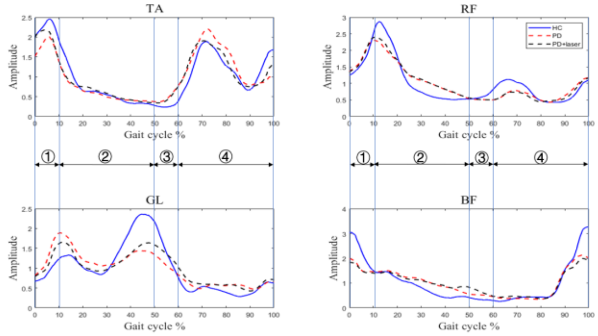

Figure 2. EMG envelope of each muscle of HC in Nolaser condition and of FOGer in both conditions. ①, ②, ③, ④ are correspond to the sub-phases of loading response, single stance, pre-swing, and swing, respectively.

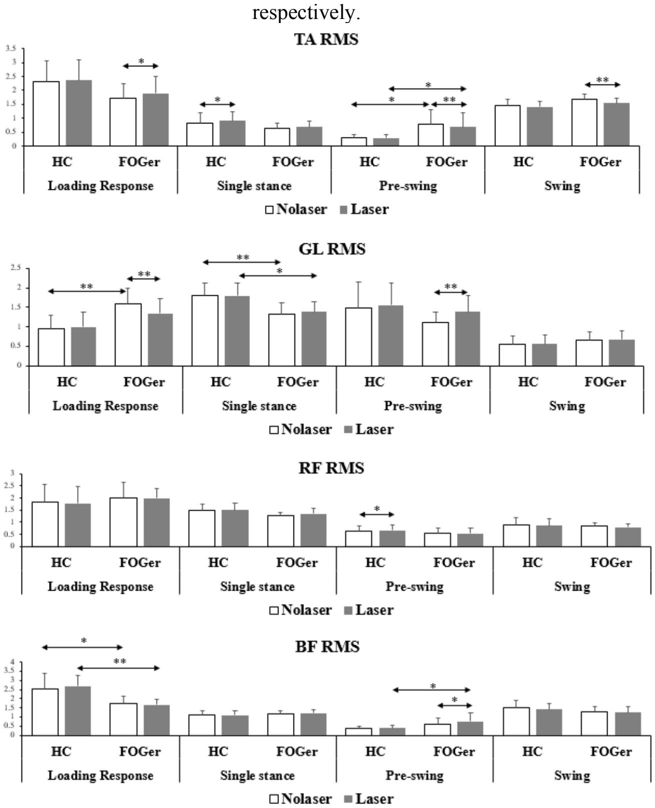

Figure 3. RMS of TA, GL, RF and BF during loading response, single stance, pre-swing, and swing phases in the two groups of Nolaser and Laser conditions. (*p<0.05, *p<0.01).

For the peak value of each EMG envelope (Fig. 4), FOGer showed a significantly lower peak value in GL and BF EMG envelope than HC (p=0.003 for GL, p=0.007 for BF) in Nolaser condition. After the laser cue was applied, there was no significant difference in the peak value of any EMG envelopes in FOGer. For the peak location of each EMG envelope, compared with HC, FOGer showed delayed peak location of TA in stance phase (p=0.071) and advanced peak location of GL(p=0.033). When FOGer walked with laser cue, the peak location of EMG envelopes shifted to the level of HC. The peak location of TA during the stance phase was significantly earlier (p=0.032), and the peak location of GL was delayed considerably (p=0.004) in FOGer under laser condition.

To further explore the relationship between improved kinematic performance and muscular activation change in laser condition, we also did the correlation analysis between the kinematic parameters and EMG parameters which were significantly changed in FOGer after the laser cue was applied (Fig. 5). The FOGer's cadence decrement in laser condition was significantly correlated with the decrement of GL RMS in loading response phase and increment of GL RMS in pre-swing phase, respectively (R=0.738, p=0.037 for GL RMS in loading response; R=-0.786, p=0.021 for GL RMS in pre-swing). Furthermore, a significantly strong correlation was observed between the decrement of GL RMS during loading response phase and the increment of GL RMS during pre-swing phase (R=-0.952, p<0.001) after the laser cue was applied in FOGer.

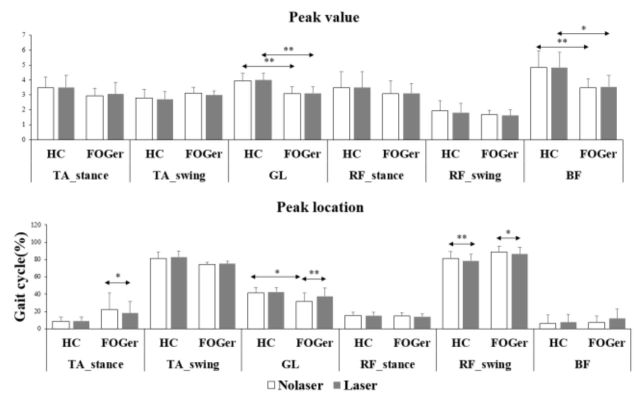

Figure 4. Peak value and peak location of each EMG envelope of HC and FOGer in Nolaser and Laser condition. (*p<0.05, *p<0.01).

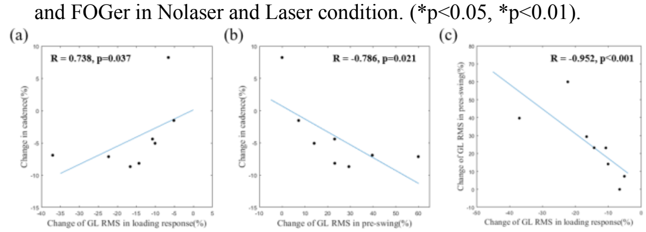

Figure 5. The correlation analysis between the change in gait performance of FOGer incurred by visual cue. (The change is normalized to the value in Nolaser condition)

IV. Discussion

This study investigated the effect of visual cues on the muscular activity of PD patients with FOG. The change of muscular activation caused by the visual cue was mainly concentrated in TA and GL during the loading response and pre-swing phase. The visual cue helped FOGer improve the muscle's activation towards a normal pattern, which is consistent with our hypothesis. The modulation of muscular activation in ankle muscles during loading response and pre-swing phase, especially the normalization of GL's activation distribution, may be the effective strategy the FOGer adopted to improve their walking performance under visual cues.

The current study shows an improvement of spatiotemporal parameters (increased stride length, speed and decreased cadence, double stance time) and a decline in FOG number in the FOGer group after laser cue, which is consistent with previous research [13,7,5]. These pieces of evidence support that visual cue was an extraordinary tool for the rehabilitation of gait in patients with FOG, albeit without a positive effect on healthy elderly.

The observed higher TA RMS in FOGer than HC during pre-swing and swing phase under Nolaser condition was consistent with previous papers [14,15]. Nieuwboer et al. [16] found a premature burst of TA during the pre-swing phase before FOG episodes. This premature phenomenon was considered as a compensatory strategy to pull the leg into swing for the weak propulsion of the body in FOGer, but it will also burden the motor system simultaneously. The function of TA is to promote the dorsiflexion of the ankle joint, so the significant decrement of TA RMS we observed during pre-swing phase in laser condition for FOGer may benefit the increment of plantarflexion in the ankle during pre-swing phase. PD patients' gait was characterized by flat-foot patterns, as the forefoot and heel strike the ground simultaneously [17]. We observed the increased TA RMS and the advanced peak location of TA EMG envelope during loading response phase in FOGer under laser condition, which may contribute to the dorsiflexion of ankle joint and appropriate timing of TA activation at the beginning of the gait cycle, and facilitate the normal heel-strike pattern [18,19].

In the present study, we observed remarkably higher GL RMS during loading response phase and lower GL RMS during pre-swing phase in FOGer than HC, which is in line with previous reports [14,18,20]. This abnormal activation pattern of GL will result in inadequate propulsion and failure to propel the body forward [16]. When FOGer walked with laser cue, the peak location of GL envelope is delayed toward HC level, and the GL RMS in loading response phase was significantly decreased, and GL RMS in pre-swing phase was significantly increased. There is also a significantly strong correlation between the decrement and increment of GL RMS in loading response phase and pre-swing phase, and the decrement of cadence was also significantly correlated with them. It is concluded that FOGer was able to voluntarily shift the activation of GL from loading response phase towards pre-swing phase under laser condition, and this modulation may be the dominant factor for the improvement of cadence. This kind of modulation in GL normalizes the distribution of GL's activation during one gait cycle, which may effectively increase the power to push the body forward. FOGer has weak muscle strength, so it may be difficult for them to increase muscle strength directly as HC, and it may be the reason why we didn't observe any significant difference of peak amplitude in the EMG envelopes for FOGer between the two conditions. For clinical treatment, future rehabilitative protocols are suggested to help patients modulate muscles, especially in the plantar flexor of the ankle joint, apart from reinforcing the muscle strength.

In the current study, we didn't observe so much significant difference in RF and BF as in GL and TA between the two conditions for FOGer. We considered that the effect of visual cues on muscular activation of FOGer was mainly concentrated on the ankle joint. However, future studies with a bigger sample size need to be carried out.

In conclusion, the main effect of visual cues on the muscular activity of PD patients with FOG may be the modulation of muscular activation of ankle joint muscles during the loading response and pre-swing phase, especially the normalization of GL's activation distribution.

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