Assessment of leg muscle activity using toe tapping in patients with Parkinson's disease: comparison of two types of toe tapping

Taniguchi, Seira

博 士 論 文

Assessment of leg muscle activity using toe tapping in patients with Parkinson's disease: comparison of two types of toe tapping

（パーキンソン病患者における下腿の筋活動評価方法について）

2020年1月11日

神戸大学大学院保健学研究科保健学専攻

谷口星来

The Journal of Physical Therapy Science

S P T S

Original Article

Assessment of leg muscle activity using toe tapping in patients with Parkinson's disease: comparison of two types of toe tapping

Seira Taniguchi, MS, RPT[1]*, Ferdinand Peper[1], Tetsuya Shimokawa[1]

[1] Kobe University Graduate School of Health Sciences: 7-10-2 Tomogaoka, Suma-ku, Kobe, Hyogo 654-0142, Japan

Abstract. [Purpose] This study investigates two types of toe tapping, i.e., "closed," with both feet on the floor, and "open," in which the foot does not touch the ground, and evaluates their usefulness in combination with monitoring of muscle activity during toe tapping. [Subjects and Methods] The study enrolled 11 patients with Parkinson's disease (PD) and 9 controls (Controls). The tibialis anterior (TA) and gastrocnemius (GS) muscle activity during toe tapping was measured using surface electromyography. [Results] In closed tapping, the minima in GS activation with the first tap was significantly higher in patients with PD than in Controls. In open tapping, the coefficient of variation (CV) of local maxima in TA activation was significantly higher in patients with PD than in Controls. In both types of tapping, the CV of extrema in GS activities increased with disease duration, but this may be due to the long-term administration of Levodopa, which itself tends to cause excessive GS activities. [Conclusion] Closed tapping is suitable for the assessment of GS activity and can detect excessive activities, which is observed as visible movement. Open tapping, on the other hand, is suitable for assessment of TA activity.
Key words: Parkinson's disease, Toe tapping, Leg muscle activity

INTRODUCTION

Parkinson's disease (PD) is clinically characterized by rigidity, akinesia, tremor, postural instability and gait disturbance. Toe tapping has been added as a relatively new assessment tool of patients[1]. Generally, it is used to measure agility in distal lower extremities[2], whereby its focus is mainly on the visual aspect of movement and rarely considers the muscle activity produced by joint movements. This study investigates two types of toe tapping, "closed," with both feet on the floor, and "open," in which the foot does not touch the ground, and evaluates their usefulness in combination with monitoring of muscle activity during toe tapping, and associating the evaluation with basic physical parameters obtained via clinical assessment of patients.

SUBJECTS AND METHODS

This study was conducted in accordance with the Declaration of Helsinki, and approved by the ethics committee of Kobe University Health Science (the approval number: 484). We obtained written informed consent from all the subjects. We enrolled 11 PD patients (age 73.0 ± 10.2 years, 6 females and 5 males, weight 48.0 ± 11.2 kg, height 156.7 ± 12.0 cm) and 9 healthy controls (age 64.6 ± 9.5, 5 females and 4 males, weight 58.1 ± 9.0 kg, height 159.3 ± 9.0 cm). We also collected information on disease duration, Hoehn and Yahr scale (H&Y scale), the Movement Disorder Society's Unified Parkinson's Disease Rating Scale (MDS-UPDRS) motor examination, and the freezing of gait questionnaires (FOG-Q). In addition,

cognitive examinations included the Mini-Mental State Examination, the Frontal assessment battery, and the Trail Making Test part A. The PD patients were all under medication with Levodopa and all testing was done in the self-assessed on-state. Subjects were excluded if they had other major clinical diseases, such as cardiovascular disease, respiratory disease, or another neurological diseases.

Figure 1 shows the two types of toe tapping tasks. One is called "closed tapping", whereby subjects are seated on a chair and the tapping foot touch the ground. Since MDS-UPDRS only contains this type of tapping, we add a new condition called "open tapping", where the tapping foot does not touch the ground in the same condition. In both types of tapping, we follow the same protocol as in MDS-UPDRS, and ask the subjects to tap their toes 10 times as much and as fast as possible. Using surface electrodes (ME3000, Mega Electronics, Ltd.), we took EMG recordings of the anterior tibialis (TA) and the medial gastrocnemius (GS), sampled at 2,048 Hz. The raw

Fig. 1. Toe tapping task.
Closed tapping (left): the ankle repeatedly moving in the range from a neutral position (a subject places the heel on the ground in a comfortable position) to maximal degree dorsiflexion, and from maximal degree dorsiflexion back to the neutral position.
Open tapping (right): the ankle repeatedly moving in the range from maximal degree plantarflexion to maximal dorsiflexion and from maximal degree dorsiflexion back to maximal degree plantarflexion.
Subjects tap the toes 10 times as big and as fast as possible.

data was full-wave rectified and low pass filtered (Butterworth 2-Hz, 3rd order, low pass filter). Data analysis was performed using MATLAB (MathWorks Inc., R2016a). The extrema over 10 times of tapping of the filtered EMG measurements in the toe tapping experiments were used to normalized the scores for each subject. The coefficient of variation (CV) and the local maxima represent the EMG bursts and the local minima represent the EMG silent periods.

The patients' characteristics and the extremes of the filtered EMG measurements in the PD patients were compared through the Wilcoxon signed-rank tests. The correlation between the PD patients' clinical characteristics and the extremes of the filtered EMG measurements of the patients was calculated by Spearman's rank correlation coefficient. All analyses were performed using statistical analysis software (SPSS version 24). The statistical significance level was set at 0.05.

RESULTS

Table 1 shows clinical demographics in patients with PD. Table 2 shows the extreme of EMG measurement parameters in two groups. In closed tapping, no significant differences were shown in the CV between the two groups, although the initial tap of the series of 10 times in the local minima in GS was significantly higher than those in the Controls (mean $0.228 \pm SD$ 0.191) vs. (mean $0.076 \pm SD$ 0.046); with p=0.038).

The CV of local maxima in TA were significantly higher in PD patients than in Controls in open tapping.

Table 3 summarizes Spearman's rank correlation. The CV of local maxima in TA (the CV-TAmax) were significantly associated with the dose of Levodopa (r=0.75; p<0.01), as well as with the H&Y scale (r=0.69; p<0.05) in open tapping. In both types of tapping, the CV of the extrema in the GS activities were significantly associated with disease duration.

Figure 2 shows an EMG signal example in one control subject and one patient with PD. In a typical example of a patient with PD, there is abnormal activity in the GS even before tapping (Fig. 2-(B,D)), while Fig. 2-(Individual with PD) describes the PD patients continued tapping more than 10 times, despite having been instructed to tap their toes only 10 times.

DISCUSSION

In closed tapping, the initial tap in the local minima in GS was significantly higher than Controls in this study. Similarly, the abnormal activity in GS even before the initiation of tapping was observed. Both results show excessively high activity in the GS. Nieuwboer et al. suggested that premature GS activation was found during the stance phase before a freeze, which was interpreted as a disordered central timing mechanism of muscle activation[3]. This may explain the excessive activities in the present study. Regarding the influences of the ankle position, Diez et al. has explained that the extended foot position causes an earlier stretching of the triceps surae muscle combined with a premature activation of GS at the beginning of the stance phase of the gait cycle[4]. In the present experimental setting, the calf muscle may already be stretched and the muscle tone be increased in the subjects because of the almost 90 degree at their ankle. Some investigators have reported that rigidity and the related increase in muscle tone were prolonged, and they inhibited relaxation, causing an intense stiffness to often occur in the distal muscle[5]. It has been reported that this may also result from intrinsic changes in PD[6, 7], but it is not caused by muscular coactivation[4]. The recoil of the elastic energy of the muscle contractile elements might benefit from the supposed increase in muscle stiffness in the combined muscle contraction[8]. In this study, this is partly the reason why the abnormal and excessive high muscle activities in the GS may result in the presence of rigidity.

In open tapping, when the ankle plantarflexion exceeds the neutral position, the TA is lengthened through extension to resist the torque plantarflexion, while the GS is shortened through contraction. Thus, the main difference between the two
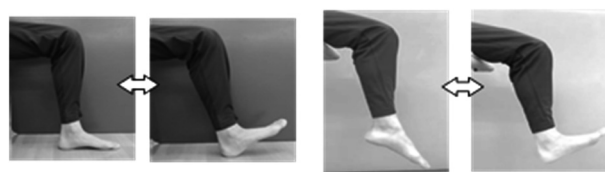
J. Phys. Ther. Sci. Vol. 30, No. 5, 2018

690

Table 1. Demographic characteristics of the patients (n=11)

H&Y scale	Disease duration (years)	MDS-UPDRS motor				FOG-Q (/24)	Levodopa (mg/day)
		Total score (/132)	Item 3.5 Rigidity (/20)	Item 3.7 Toe tapping (/8)	Item 3.14 Bradykinesia (/4)		
2.8 ± 0.4	8.6 ± 5.4	39.9 ± 13.4	7.4 ± 3.8	3.2 ± 1.5	1.5 ± 1.2	9.4 ± 6.8	350.0 ± 136.5

Results are given as mean ± SD.

Table 2. The extreme of EMG measurements parameter in two groups

Task	Muscles	CV of the extrema	PD patients	Controls
Closed tapping	TA	Maxima	0.16 ± 0.07	0.13 ± 0.05
		Minima	−2.31 ± 4.91	0.12 ± 1.36
	GS	Maxima	0.22 ± 0.12	0.23 ± 0.11
		Minima	0.29 ± 0.16	0.41 ± 0.15
Open tapping	TA	Maxima	0.19 ± 0.09	0.12 ± 0.04*
		Minima	0.08 ± 1.37	0.21 ± 0.48
	GS	Maxima	0.24 ± 0.15	0.19 ± 0.07
		Minima	0.46 ± 0.42	4.47 ± 11.63

Results are given as mean ± SD.
*$p<0.05$ (Mann-Whitney U test).

Table 3. Spearman's rank correlation coefficients between Patients' characteristics and the extreme of filtered EMG measurements

Task	Muscles	CV of the extrema	Disease duration (years)	H&Y scale	Levodopa (mg/day)
Closed tapping	TA	Maxima	0.10	−0.18	0.21
		Minima	0.41	0.42	0.21
	GS	Maxima	0.66*	0.47	0.33
		Minima	0.71*	−0.08	0.35
Open tapping	TA	Maxima	0.32	0.69*	0.75**
		Minima	−0.20	0.36	−0.23
	GS	Maxima	0.66*	0.19	0.00
		Minima	0.69*	0.16	0.18

*$p<0.05$; **$p<0.01$.

types of tapping appears to be reflected in differences in how the TA contracts. In the present study (Table 2), the CV of local maxima in TA (the CV-TAmax) were significantly higher in PD patients (0.19 ± 0.09) than Controls (0.12 ± 0.04). The CV-TAmax indicated a burst of EMG, and the associated TA contractions form the basic distinction between the two types of tapping. It is well known that during human gait the leg muscle undergoes a phase-dependent contraction in the gait cycle. In healthy subjects, the TA is mainly activated in the swing phase and the early stance phase[9], and it has a strong forward momentum during the stance phase when the body moves forward. However, in PD patients, the TA activity was absent or had a reduced amplitude during the stance phase[10], while it was over-activated in the swing phase[4, 11]. Furthermore, the stronger TA activation in PD patients may in part compensate for the impaired leg extensor activation[12]. In this study, a moderately strong association was shown between the CV-TAmax and the dose of Levodopa, as well as between the CV-TAmax and the H&Y scale (Table 3). This may explain the relationship between TA activity and medication. Previous work has reported that the TA was more influenced by Levodopa, and that low magnitude activation bursts and a high variation in the discharge rate of single motor units are the main EMG features of motor unit dysfunction[13]. Some studies suggested that this tendency occurs at faster movements[14]. In this study, likewise, subjects were required to have periodic strong contractions over a wide angle at maximal speed. For these reasons, a highly variable TA activity may compensate for motor unit dysfunction, and also influence the muscle weakness of the dorsiflexion in PD patients. In both types of tapping, the CV of extrema in GS activities are correlated with the disease duration. This may be due to neurological changes in the GS, i.e., the rigidity resulting from the side effect of long-term administration of Levodopa rather than from the main effects of Levodopa.

We conclude that closed tapping is suitable for the assessment of GS activity and that it can detect excessive activities.
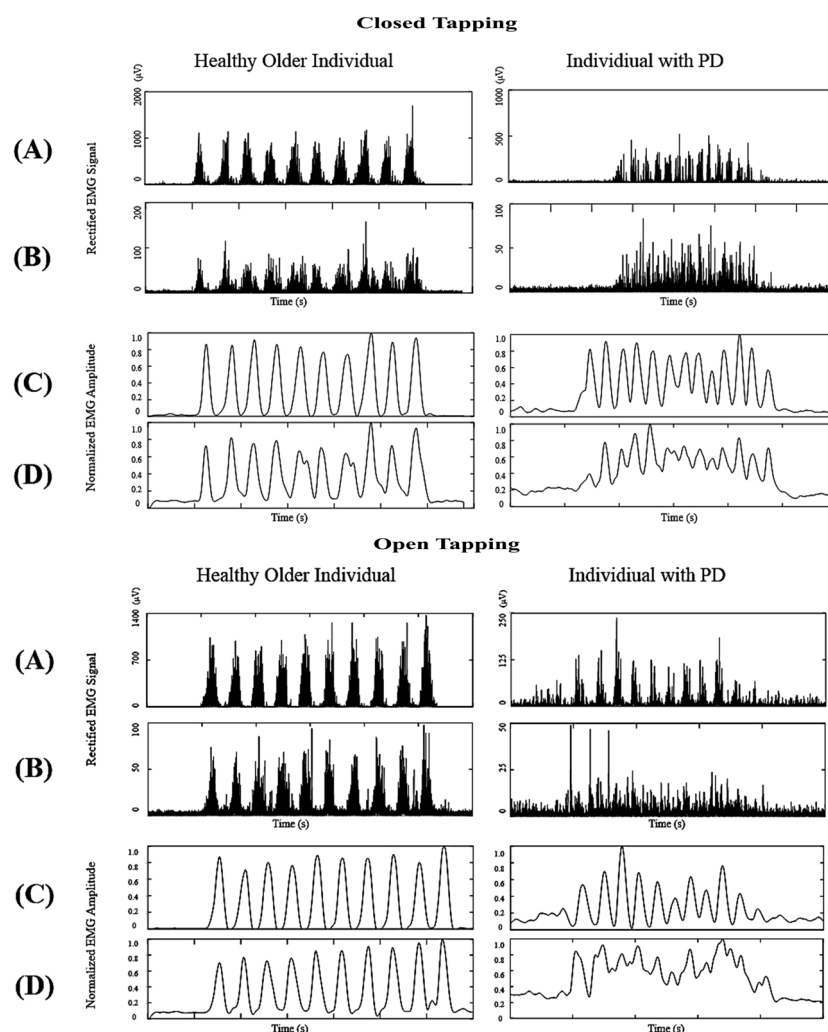
Fig. 2. Example of the surface electromyography recordings of the patient with Parkinson's diseases and healthy control subject.

Rectified the surface electromyography (EMG) signal of tibialis anterior (A), gastrocnemius muscles (B), normalized EMG amplitude in tibialis anterior (C), and in gastrocnemius muscles (D).

The represented patient (individual with PD) in the affected side leg muscle during toe tapping.

Open tapping, on the other hand, is suitable for the assessment of TA activity.

In both types of tapping, we found that the CV of extrema the GS activities increased with the disease duration, but this may be due to the side effects that long-term administration of levodopa by itself tends to cause excessive GS activities.

We will be able to know the variable disposition of the leg muscle activity as the visual aspect of movement, and predict the characteristics of the gait pattern through the surface electromyography recordings during toe tapping.

Conflict of interest

We declare that we have no conflict of interest.

REFERENCES

1) Goetz CG, Tilley BC, Shaftman SR, et al. Movement Disorder Society UPDRS Revision Task Force: Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): scale presentation and clinimetric testing results. Mov Disord, 2008, 23: 2129–2170. [Medline] [CrossRef]

J. Phys. Ther. Sci. Vol. 30, No. 5, 2018

692

2) Gunzler SA, Riley D, Walter E, et al.: Comparison of the toe tapping component of the MDS-UPDrs motor scale with leg agility and finger tapping. Mov Disord, 2010, 25, Suppl 2: 348–389.

3) Nieuwboer A, Dom R, De Weerdt W, et al.: Electromyographic profiles of gait prior to onset of freezing episodes in patients with Parkinson's disease. Brain, 2004, 127: 1650–1660. [Medline] [CrossRef]

4) Dietz V, Quintern J, Berger W, IETZ V: Electrophysiological studies of gait in spasticity and rigidity. Evidence that altered mechanical properties of muscle contribute to hypertonia. Brain, 1981, 104: 431–449. [Medline] [CrossRef]

5) Burleigh A, Horak F, Nutt J, et al.: Levodopa reduces muscle tone and lower extremity tremor in Parkinson's disease. Can J Neurol Sci, 1995, 22: 280–285. [Medline] [CrossRef]

6) Dietz V, Berger W, Horstmann GA: Posture in Parkinson's disease: impairment of reflexes and programming: Ann Neurol, 1988, 24, 5: 660–669. [Medline] [CrossRef]

7) Glendinning DS, Enoka RM: Motor unit behavior in Parkinson's disease: Phys Ther, 1994, 74, 1: 61–70. [Medline] [CrossRef]

8) Pedersen SW, Oberg B: Stretch-shortening contraction in Parkinson patients: evidence of normal muscle contraction execution with low efficiency. Scand J Rehabil Med, 1997, 29: 251–255. [Medline]

9) Elble RJ, Moody C, Leffler K, et al.: The initiation of normal walking. Mov Disord, 1994, 9: 139–146. [Medline] [CrossRef]

10) den Otter AR, Geurts AC, Mulder T, et al.: Speed related changes in muscle activity from normal to very slow walking speeds. Gait Posture, 2004, 19: 270–278. [Medline] [CrossRef]

11) Albani G, Sandrini G, Künig G, et al.: Differences in the EMG pattern of leg muscle activation during locomotion in Parkinson's disease. Funct Neurol, 2003, 18: 165–170. [Medline]

12) Dietz V, Zijlstra W, Prokop T, et al.: Leg muscle activation during gait in Parkinson's disease: adaptation and interlimb coordination. Electroencephalogr Clin Neurophysiol, 1995, 97: 408–415. [Medline] [CrossRef]

13) Cioni M, Richards CL, Malouin F, et al.: Characteristics of the electromyographic patterns of lower limb muscles during gait in patients with Parkinson's disease when OFF and ON L-Dopa treatment. Ital J Neurol Sci, 1997, 18: 195–208. [Medline] [CrossRef]

14) Hallett M, Khoshbin S: A physiological mechanism of bradykinesia. Brain, 1980, 103: 301–314. [Medline] [CrossRef]