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A Simple Procedure Using Auditory Stimuli to Improve Movement in Parkinson's Disease: A Pilot Study

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Abstract

It has been suggested that sequential movements in Parkinsonian patients might be improved by the effects of external rhythmic cues, either visual or acoustic, acting as a sort of timekeeper. In line with that idea, we have developed a portable system which allows the patient suffering from bradykinesia and rigidity to initiate appropriate auditory stimulation when he/she is not able to move. Here we present data from six Parkinson's Disease (PD) patients studied with surface electromyography, while walking along an 8.5m walkway. All showed remarkable improvement in the EMG parameters studied while using the device. The results are consistent with prior reports on rhythmic auditory facilitation in Parkinson's disease gait, and suggest that this represents a novel and inexpensive tool to help people afflicted by PD in daily motor performance.

Introduction

Patients with Parkinson's disease (PD) have difficulty with self-initiating movements, such as walking, that result in a slow, stumbling gait and even periods of complete akinesia. Parkinsonian hypokinesia renders difficult the automatic execution of elementary movements and the specific performance of motor tasks; the harmony of repetitive movements is disjointed in rhythm, speed and amplitude. However, motor performance can be improved when external stimuli are provided, such as by lines on the floor (Martin, 1967) or by acoustic cues (Georgiou et al, 1993; Thaut et al, 1996; McIntosh et al, 1997). The effectiveness of utilising sensory systems - for example vision - to facilitate locomotor activity was first described by Martin (1967) over 35 years ago. More recently, Richards et al (1992) compared the effects of visual and auditory cues on various gait parameters in patients with Parkinson's disease on and off levodopa. In that study patients walked faster with both cues. These data strongly suggests that the Parkinsonian brain may be capable of some reorganization (or re-routing) in order to initiate or facilitate performance of volitional movements. In PD the widespread connections between polymodal cortical areas (motor, visual, vestibular and auditory) and the basal ganglia seem to be functionally preserved (Alexander et al, 1986; Playford et al, 1992; Bremmer et al, 2001), and the basal ganglia and cerebellum are good candidates for internal timekeeping operations (Rao et al, 2001). For this study, we reasoned that the availability of external cues (acting as an external timekeeper), initiated by the PD patient, could be of benefit in overcoming problems of movement.

Methods

Six patients (between 58 and 65 years of age, 3 males, 3 females) with a clinical diagnosis of idiopathic Parkinson's disease were studied. Five healthy, age-matched, normal subjects were also studied. Informed consent for participation was obtained from all individuals and protocol procedures were reviewed and approved by the University of Coruña ethical board and were in accordance with The Declaration of Helsinki. All patients had a normal neurological examination and none had a history of neurological, cardiovascular or psychiatric disturbance

other than Parkinson's disease. All patients were on medication and rigidity and bradykinesia were major features of the symptomatology. A Unified Parkinson's Disease Rating Scale (UPRDS) motor score was recorded and the average patient UPRDS was 50 (range 30-70). The average Hoehn and Yahr score was 3.2 (range 3-4).

Patients were tested in the morning always during the ON period, 60 minutes after medication. They walked along an 8.5 m walkway, turned 180° at the walkway end and returning to starting position. Electromyographic activity (EMG) of two leg muscles (Tibialis Anterior and Gastrocnemius) was recorded by mean of surface electrodes following standard procedures (Cram and Kasman, 1998). Quantification of the surface electromyographic recording was done using the integral average (μV/sec) of the EMG raw signal (Cram and Kasman, 1998). Patients did not expect to obtain any direct and immediate benefit from this experiment, and it was considered as a system to evaluate gait. We studied the following temporal parameters: interval between burst of EMG activity, slope of each burst and its duration. In control trials, no external auditory cues were available. In test trials, the patients were asked to proceed in the presence of an external rhythm (click tone) at fixed frequency of 100 click/min, a standard value for normal elderly walking cadence (Zatsiorky et al, 1994). The tone was delivered by a device constructed in-house, consisting of a battery operated metronome and small headphones, that was controlled by the patient. Patients were permitted a 10 minute rest between trial types. We compared performance during the task with and without stimulation using the Mann-Whitney *U* and Wilcoxon tests for a $p \leq 0.05$.

Results

All patients showed significant improvement in the recorded EMG parameters while the device was in use. Figure 1 illustrates the changes obtained in the surface electromyogram in one patient. The regularity of muscle activation when the device is ON shows a very clear change. The sequential patterns that characterize the agonist-antagonist activity are clearly disrupted in the control conditions and in particular, activation of the gastrocnemius is very poor. With acoustic stimulation this activation clearly improved. This is a very important finding, because whatever mechanisms are involved, this suggests that our manipulation (sensory stimulation) is affecting the final output of the motor system at the level of the motor unit, which, in fact, has been demonstrated to be affected in patients with idiopathic PD (Caviness et al, 2000).

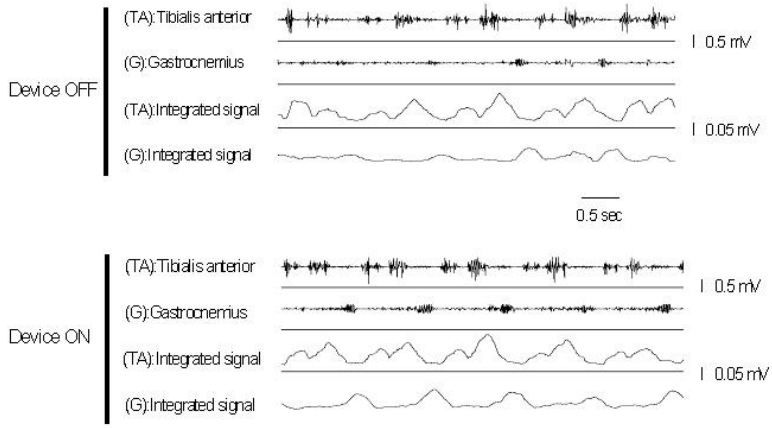

Figure 1 Representative segment of EMG activity recorded in one patient in two different conditions: device providing acustic stimulation ON and OFF. Note the different pattern of EMG activation when the stimulator is ON specially for the gastrocnemius muscle.

The following changes in measured EMG parameters were found (expressed as % change for all patients; significant for $p \leq 0.05$): *the interval between EMG responses decreased with stimulation* (20% TA; 38%

G); *the slope of EMG activation increased* (32% TA, and 29% G); and *the duration of each burst of EMG activation*

Pt #	**Interval between EMG responses (sec)** *Mean/SD/Coefficient of variability*		**Slope of EMG:** *Mean/SD/Coefficient of variability*		**Duration of EMG activation (sec):** *Mean/SD/Coefficient of variability*	
	Device OFF	Device ON	Device OFF	Device ON	Device OFF	Device ON
1	(TA):*1.48/0.12/8.1* (G): *1.45/0.08/5.5*	*1.19/0.06/5.04* *1.20/0.06/5*	(TA):*0.56/0.16/28.5* (G): *0.08/0.04/50*	*0.85/0.19/22* *0.11/0.04/36*	(TA):*1.19/0.14/11.7* (G): *1.45/0.08/5.5*	*0.99/0.084/8* *1.14/0.05/4.3*
2	(TA):*1.53/0.11/7.2* (G): *1.54/0.18/11.7*	*1.25/0.06/4.8* *1.28/0.09/7*	(TA):*0.78/0.21/27* (G): *0.13/0.03/23*	*0.87/0.13/15* *0.23/0.04/17*	(TA):*0.62/0.22/35.5* (G): *1.36/0.13/9*	*0.54/0.16/29.6* *1.19/0.05/4.2*
3	(TA):*1.65/0.14//8.48* (G): *1.55/0.14/9*	*1.17/0.08/6.8* *1.23/0.09/7.3*	(TA):*0.41/0.26/63* (G): *0.2/0.05/24*	*0.53/0.3/63* *0.25/0.04/16*	(TA):*0.81/0.4/52* (G): *1.32/0.12/9.1*	*0.57/0.13/23* *1.08/0.9/8.3*
4	(TA):*0.86/0.04/4.7* (G): *0.89/0.08/9*	*0.78/0.03/3.8* *0.79/0.03/3.4*	(TA):*0.3/0.07/23* (G): *0.18/0.08/44*	*0.4/0.06/15* *0.22/0.05/23*	(TA):*0.39/0.11/28.2* (G): *0.69/0.11/16*	*0.29/0.05/17* *0.49/0.07/14*
5	(TA):*1.2/0.06/5* (G): *1.22/0.08/6.6*	*1.1/0.045/4* *1.17/0.06/5.1*	(TA):*0.2/0.08/38* (G): *0.28/0.07/25*	*0.3/0.07/23* *0.34/0.07/20*	(TA):*0.4/0.09/10.8* (G): *0.74/0.08/11*	*0.33/0.03/8* *0.68/0.05/7.3*
6	(TA):*1.4/0.08/6.4* (G): *4/0.07/5*	*1.1/0.05/4.5* *1.0/0.03/3*	(TA):*0.6/0.19/31* (G): *0.15/0.05/33*	*0.78/0.16/20* *0.20/0.04/20*	(TA):*0.65/0.21/32.3* G): *1.00/0.13/13*	*0.55/0.12/18* *0.65/0.05/7.6*

TA = Tibialis anterior G = Gastrocnemius

Table 1 Changes observed for each patient in two different conditions: With and without stimulation

decreased (23% TA and 20% G). Overall, it is very clear that the precise timing of activation improved because the variability of each parameter significantly decreased and this is shown in Table 1. Here we report the changes observed for each subject expressed as the mean, the standard deviation and the coefficient of variability (a measurement for temporal stability = standard deviation/mean*100) (Hausdorff et al, 1998).

We investigated the effects of using the device on the age-matched normal control subjects. After repeating the same protocols we did not observe any significant difference between the data obtained with and without stimulation. Figure 2 shows an example from control subject number one.

We have used the coefficient of variability as a well known indicator for temporal stability (Hausdorff et al, 1998). Figure 3

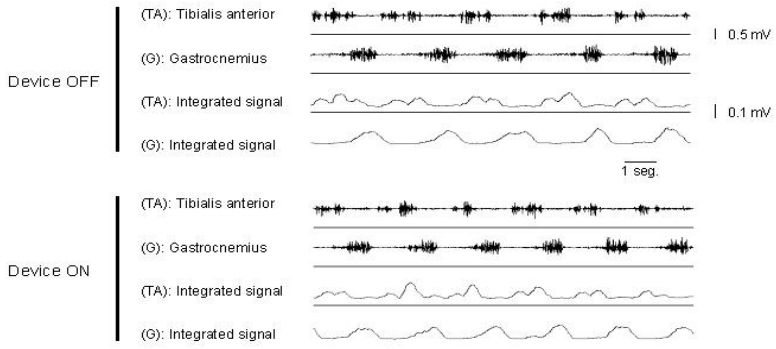

Figure 2 Representative segment of EMG activity recorded in one healthy control in two different conditions: device providing acoustic stimulation ON and OFF. There is no difference between both conditions.

illustrates how this indicator changes for patients with and without stimulation, and also in comparison to control subjects. With acoustic stimulation, the coefficient of variability improved for each of the parameters studied and reached values very close to those recorded for control subjects (for which stimulation and control situations were not statistically different).

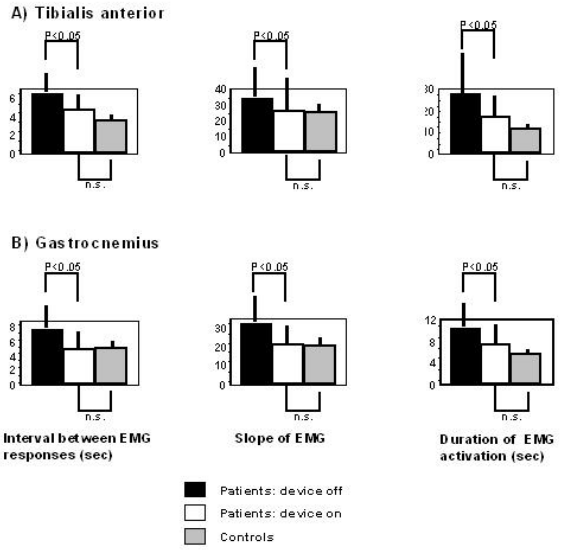

Figure 3. This figure shows the changes observed in the coefficient of variabilty of the whole population of patients when the device is ON (versus device OFF) and the comparison with the values obtained for the control subjects. For the parkinsonian patients all the studied parameters when the device was ON move toward normal values.

Discussion

These data were in agreement with findings by others (Thaut et al, 1996; McIntosh et al, 1997) who used an auditory stimulation training program of 3 weeks duration, based upon rhythmic stimuli embedded in a musical structure (a technique called RAS). These authors found that gait velocity, cadence and stride length improve in the vast majority of patients. However, it is important to note that in our study the patients had never practiced protocol described here prior to testing, and therefore undertook no training whatsoever. Furthermore, it is important to bear in mind that the patients did not expect any benefit from this experiment, just a way to study gait. Also it is interesting that the external stimulation only improves the EMG patterns and the internal timing of patients because experiments done in control healthy elderly, did not show any difference. Similar results on electrical muscle activity were previously reported by Thaut and co-workers (Miller et al, 1996). They found a reduction in EMG shape variability in patients with Parkinson's disease during RAS cued walking, indicating, as we suggest, more consistent motor unit recruitment.

There is some evidence in the literature that rhythmic sound patterns can increase the excitabilty of spinal motor neurons via the reticulospinal pathway reducing the time required for the muscle to respond to a given motor command. It has been shown, for instance, that auditory signals reduced reaction time in a voluntary motor task (Paltsev and Elner, 1967). Also auditory facilitation of the H-reflex has been shown (Rossignol and Jones, 1976) and movement related gastrocnemius activity occurred during the period when the H-reflex was maximal, suggesting that descending motor commands became entrained to the auditory pacing signal so as to make the best use of a potential audiospinal facilitation effect.

Studies in monkeys have shown that movement related phasic discharge of pallidal neurons may serve as an internal cue to the supplementary motor area signalling the end of one movement and allowing the onset of the next (Brotchie et al, 1991). Several authors have suggested that external cues (e.g. sound) provide a trigger in Parkinson's disease to switch between the different components of a movement sequence, avoiding in this way the defective internal pallidocortical projections (Morris et al, 1994; Cunnington et al, 1995).

Based on clinical and experimental data, it has been suggested that bradykinesia or slow movement initiation in Parkinson's disease (in general self-initiated movements) may reflect impaired input from cortical areas, more specifically the medial premotor system centred around the putamen-thalamus-supplementary motor area loop (Goldberg, 1985; Dick et al, 1989; Jahanshahi et al, 1995). However, the lateral premotor system involved in externally triggered movements seems not to be impaired in Parkinson's disease (Jahanshahi et al, 1995). This cortical zone, centered in the lateral premotor cortex receives its main input from the parietal cortex and cerebellum (Goldberg, 1985). We suggest that it is possible that the external stimulation works as a trigger, operating through the intact lateral premotor system, which is able to overcome (partially at least) the motor program deficits due to supplementary motor area malfunctioning. In fact, it is interesting to note that primary motor cortex itself functions normally in Parkinson's disease (Dick et al, 1984; Jenkins et al, 1992; Playford et al, 1992). Our results highlight the importance of external rhythmic stimulation as a putative tool for the management of patients with Parkinson's disease. However, the precise mechanisms underlying the positive effects shown here remain to be explored.

Conclusions

In addition to the typical neurochemical deficits, abnormal motor performance in Parkinson's Disease results from impaired motor programming, with functional alterations of the supplementary motor area and pre-motor cortex resulting in a failure of the internal rhythm formation process. Our most important finding is that individuals with Parkinson's disease improved the temporal motor parameters studied during walking when receiving external auditory cues. These results are consistent with prior reports of rhythmic auditory facilitation in Parkinson's disease gait, and suggest that auditory paced stimulation is likely to be a novel and inexpensive tool for improving important gait parameters and for gait rehabilitation.

References

Alexander GE, DeLong MR, Strick PL: Parallel organization of functionally segregated circuits linking basal ganglia and cortex. Annu Rev Neurosci 1986; 9:357-381.

Bremmer F, Schlack A, Jon Shah N, et al: Polymodal motion processing in posterior parietal and premotor cortex: A Human fMRI study strongly implies equivalencies between humans and monkeys. Neuron 2001; 29: 287-296.

Brotchie P, Iansek R, Horne MK: Motor function of the monkey globus pallidus. 2. Cognitive aspects of movement and phasic neuronal activity. Brain 1991; 114:1685-1702.

Caviness JN, Smith BE, Stevens JC, et al: Motor unit changes in sporadic idiopathic Parkinson's disease. Mov Disord 2000; 15:238-243.

Cram JR, Kasman GS: The basic of surface electromyography: Instrumentation. In: Cram JR, Kasman GS, Holtz J, eds. Introduction to surface electromyography. Gaithersburg, Maryland: Aspen Publishers Inc; 1998:43-79.

Cunnington R, Iansek R, Bradshaw JL, Phillips JG: Movement-related potentials in Parkinson's disease. Presence and predictability of temporal and spatial cues.Brain. 1995;118:935-50

Dick JP, Cowan JM, Day BL, et al.: The corticomotoneurone connection is normal in Parkinson's disease. Nature 1984; 310: 407-409.

Dick JPR, Rothwell JC, Day BL, et al: The Bereitschaftspotential is abnormal in Parkinson's disease. *Brain* 1989; 112:233-244.

Georgiou N, Iansek R, Bradshaw JL, et al: An evaluation of the role of internal cues in the pathogenesis of parkinsonian hypokinesia. Brain 1993; 116:1578-1587

Goldberg G: Suplementary motor area structure and function: review and hypotheses. Behav Brain Sci 1985; 8:567-615.

Hausdorff JM, Cudkowicz ME, Firtion R, et al: Gait variability and basal ganglia disorders: stride to stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. Mov Disord 1998; 13:428-437.

Jahanshahi M, Jenkins IH, Brown RG, et al: Self-initiated versus externally triggered movements. I. An investigation using measurement of regional cerebral blood flow with PET and movement-related potentials in normal and Parkinson's disease subjects. *Brain* 1995; 118:913-933.

Jenkins IH, Fernandez W, Playford ED, et al.: Impaired activation of the supplementary motor area in Parkinson's disease is reversed when akinesia is treated with apomorphine. *Ann Neurol* 1992; 32:749-757.

Miller RA, Thaut MH, McIntosh GC, Rice RR: Components of EMG symmetry and variability in parkinsonian and elderly gait. Electroencephalogr Clin Neurophysiol 1996; 101:1-7.

Martin JP: The basal ganglia and posture. London: Pitman; 1967.

McIntosh GC, Brown SH, Rice RR, Thaut MH: Rhythmic auditory-motor facilitation on gait patterns in patients with Parkinson's disease. J Neurol Neurosurg and Psychiat 1997; 62:22-26.

Morris ME, Iansek R, Matyas TA, Summers JJ: The pathogenesis of gait hypokinesia in Parkinson's disease. Brain. 1994;117:1169-81.

Paltsev YI, ElnerAM: Change in the functional state of the segmental apparatus of the spinal cord under the influence of sound stimuli and its role in voluntary movement. Byophysics 1967; 12:1219-1226.

Playford E D, Jenkins IH, Passingham RE, et al: Impaired mesial frontal and putamen activation in Parkinson's disease: a positron emission tomography study. Ann Neurol 1992; 32:151-161.

Rao SM, Mayer AR, Harrington DL: The evolution of brain activation during temporal processing. Nat Neurosci 2001; 4:17-23.

Richards CL, Malouin F, Bedard PJ, Ciono M: Changes induced by L-dopa and sensory cues on the gait of parkinsonian patients. In: Woollacott M, Horak F, eds. Posture and gait: control mechanisms. Vol II. Eugene OR: University of Oregon Books 1992: 126-129.

Rossignol S, Jones GM: Audio.spinal influences in man studied by the H-reflex and its possible role on rhythmic movements synchronized to sound. Electroencephalogr Clin Neurophysiol 1976; 41:83-92

Thaut MH, McIntosh GC, Rice RR, et al: Rhythmic auditory stimulation in gait training for Parkinson's disease patients. Mov Disord 1996; 11:193-200.

Zatsiorky VM, Werner SL, Kaimin MA: Basic kinematic of walking. Step length and step frequency. A review. J Sports Med 1994; 34:109-13.