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Rotating treadmill training reduces freezing in Parkinson disease: preliminary observations

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Abstract

Two subjects with Parkinson disease (PD) who had difficulty turning, and freezing of gait triggered by turning, participated. Subjects completed four blocks of turning trials. Three blocks were conducted in the absence of treadmill intervention. Both subjects had consistent freezing across blocks prior to training and evidenced more freezing when turning left than right. The final block of turns was performed after 10–15 minutes of training leftward turning on a rotating circular treadmill. Following training: 1) neither subject froze during leftward turns, 2) muscle activity normalized, and 3) turning times decreased for leftward turns.

Keywords

Turning; Freezing; Parkinson disease; Rotating Treadmill Short title

Introduction

Many individuals with Parkinson disease (PD) experience difficulty turning and freezing of gait that can lead to falls. Falls during turning are eight times more likely to result in hip fracture than falls during straight walking [1] and individuals with PD are 3.2 times more likely to sustain a hip fracture than people of similar age without PD [2]. The cost of care for hip fractures in PD is approximately \$192 million per year [2,3]. Given the substantial personal and financial costs associated with this problem, it is clear that strategies are needed to address turning difficulties in order to reduce falls and fractures.

In previous work we have proposed the use of a rotating treadmill to address difficulties with freezing and turning in individuals with PD [4]. Following stepping in-place on a rotating treadmill, control subjects asked to walk in a straight line without vision will inadvertently turn in circles [5]. This response, called podokinetic after-rotation (PKAR), represents an adaptation to the treadmill stimulus.

The rotating treadmill may be an excellent tool for gait rehabilitation in PD. We have demonstrated that kinematic patterns employed during PKAR following exposure to the rotating treadmill are similar to those used in voluntary turning [4]. Furthermore, we have shown that people with mild PD are able to adapt to walking on the rotating treadmill and demonstrate robust PKAR [6]. This latter finding is crucial because successful rehabilitation is dependent on the individual's ability to adapt and modify behavior with treatment. The

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purpose of the present study was to gather preliminary data on the effects of rotating treadmill training in individuals with advanced PD who have freezing of gait and difficulty with turning. We hypothesized subjects would show reduced freezing during turning following a period of training on the rotating treadmill.

Methods

Subjects

We recruited 13 patients with PD who reported having consistent freezing with turns, but only two of the 13 people recruited demonstrated consistent freezing in our laboratory setting. Both of these subjects had a long history of PD and substantial on-period freezing, i.e. freezing that occurs despite taking medication. This freezing was triggered by turning in both subjects. These two subjects with idiopathic PD were tested approximately an hour after the first morning dose of their normal medications. Subject demographics are provided in Table 1. This study was approved by the Human Studies Committee of the Washington University School of Medicine, and subjects provided informed consent prior to participation.

Data Collection

Each subject completed four blocks of turning trials. Each block included 20 in-place turns, 10 leftward and 10 rightward, of 180° amplitude and 10 trials, 5 leftward and 5 rightward, of the Timed Up & Go (TUG) [7]. The TUG requires the subject to start from a seated position and the examiner times how long it takes the subject to stand up, walk to an object 3m away, turn around, walk and sit back in the chair. Three consecutive blocks were conducted in the absence of the treadmill intervention to determine consistency of performance across blocks and the potential influence of practice on performance. The fourth block of turns was performed after rotating treadmill training. During rotating treadmill training, subjects walked in place on the perimeter of the rotating treadmill which has a diameter of 122 cm (Neuro Kinetics, Inc., Pittsburgh, PA). Subject 1 walked for 10 minutes and Subject 2 for 15 minutes on a disk rotating clockwise at 45 degrees/sec. Walking on a rotating treadmill that turns in the clockwise direction results in a PKAR response of turning to the left. Both subjects had more difficulty turning to the left and that is why we chose to train leftward turning using the clockwise-rotating treadmill. Subjects walked for as long as they were able, up to 5 minutes, and were given rests as needed until they had accumulated 10 or 15 min, respectively, of total treadmill time. For more detailed information on experimental setup, refer to Hong et al [6].

During trials of turning we recorded surface EMG from the vastus lateralis bilaterally and foot positions were recorded with a motion capture system (Motion Analysis Corporation, Santa Rosa, CA) using reflective markers placed on the first metatarsal and calcaneus bilaterally. EMG and kinematic data were synchronously sampled at 1000 Hz and 100 Hz respectively. Kinematic data were used to identify freezing episodes which were defined as coming to a complete stop in the transverse plane in the midst of an ongoing turn. TUG trials were timed with a stopwatch. Leftward and rightward turns were alternated for all turning and TUG trials.

Data Analysis

Number of trials on which at least one freeze occurred was tabulated for each block. DataPac 2K2 (Run Technologies, Mission Viejo, CA) was used for kinematic and EMG analysis. All signals were digitally low-pass filtered at 20Hz (4th order, zero-lag Butterworth filter). Turn onsets were automatically identified using the vertical coordinate of the toe markers via a threshold criterion method. After placing an event at a threshold of 10 mm, the first derivative of the toe marker in the vertical coordinate was determined and the onset event repositioned to the time just prior to the threshold when the rate of change increased from zero. Each marked onset was visually confirmed. EMG signals were root mean square averaged with a time

constant of 10 ms. Burst onsets and offsets were defined at a threshold of three standard deviations above baseline and were visually confirmed. Bursts that began up to 500 ms prior to turn onset were included in the analysis. Burst durations of the bilateral vastus lateralis muscles were averaged within trials and across trials turning in the same direction. Therefore, burst durations for leftward turns were averaged separately from those for rightward turns. We calculated coactivation indices for the left- and rightward turns separately. Taking the left vastus lateralis as the reference muscle, we calculated the percentage of the burst duration of the left vastus lateralis muscle that had overlapping activity with the contralateral vastus lateralis. This was calculated for every burst and averaged across bursts within trials and across same direction turning trials.

Results

Prior to training, subjects demonstrated consistent turning performance across consecutive blocks and evidenced no practice effect. The number of freezing trials when turning leftward for consecutive blocks was 10/10, 10/10, and 9/10 for Subject 1 and 5/10, 4/10, and 6/10 for Subject 2. Figure 1A illustrates a single trial of turning to the left before training for Subject 1. Note the two periods of freezing marked by asterisks. During these freezes the left foot remained flat on the floor and the right toe remained on the floor while the right heel moved up and down. There was high amplitude, rapid bursting activity of the vastus lateralis bilaterally. This muscle activity was characterized by coactivation of the left and right vasti during freezes rather than alternating activity between the left and right sides.

Following training neither subject froze during leftward turns, the direction of turning trained. Figure 1B illustrates a single trial of turning to the left after training in Subject 1. There was no freezing and muscle bursts were of lower amplitude and longer duration. The time to execute this turn was much lower than the time to execute the same turn prior to training.

Pooled data across multiple trials and across subjects demonstrated decreased variability in vastus lateralis burst durations after training when turning to the left. Mean burst durations for leftward turns, before and after training, were 688 ± 455 (mean $\pm$ SD) and 894 ± 174 for Subject 1 and 479 ± 394 and 811 ± 263 for Subject 2. The group means for leftward turning were 583 ± 425 ms before training and 852 ± 218 ms after training. Mean burst durations for rightward turns, before and after training, were 675 ± 385 and 869 ± 413 for Subject 1 and 531 ± 304 and 751 ± 230 for Subject 2. The group means for rightward turning were 603 ± 345 ms before training and 810 ± 322 ms after training. After training mean burst durations increased for both left- and rightward turns however, the variability only decreased for the leftward turns.

Pooled data across multiple trials and across subjects demonstrated decreased coactivation indices after training when turning to the left. Coactivation indices for leftward turns, before and after training, were 53.2 ± 17.6 and 32.7 ± 17.2 for Subject 1 and 50.3 ± 15.6 and 42.9 ± 9.3 for Subject 2. The group means for leftward turning were 51.8 ± 15.8 before training and 35.1 ± 14.1 after training (Figure 1C). Coactivation indices for rightward turns, before and after training, were 45.1 ± 17.5 and 51.4 ± 11.6 for Subject 1 and 55.3 ± 15.7 and 55.0 ± 12.9 for Subject 2. The group means for rightward turning were 52.3 ± 16.6 before training and 52.0 ± 11.7 after training (Figure 1C).

TUG time improved from the pre- (14.2 ± 0.9 s) to the post-training block (12.8 ± 0.5 s) for leftward turning trials. TUG time did not change for rightward turning trials (Figure 2).

Discussion

Difficulty turning is a common problem in PD. Self-reported turning difficulty is a sensitive indicator of freezing and falling [8]. On-period freezing in PD is particularly problematic

because, by definition, it does not respond to medications [9]. As such, the development of novel rehabilitative interventions to address these problems is warranted. This is the first evidence demonstrating immediate reductions in freezing and improvements in functional mobility following rotating treadmill training in two individuals with PD who had pronounced on-period freezing.

Mechanisms of Freezing and Potential Relationship to Rotating Treadmill Intervention

The underlying impairments that lead to freezing have not been clearly identified but several theories exist. One proposition is that freezing results from a combination of hypokinesia and the sequence effect [9]. Hypokinesia refers to the fact that steps are smaller than normal at the outset of walking and the sequence effect refers to the fact that steps become progressively smaller over the course of a walking trial. Interventions to enhance either baseline step size or to maintain the step size across a trial could both contribute to a reduction of freezing. The rotating treadmill may serve as a cue to help lengthen and standardize step lengths.

Freezing of gait is also associated with gait asymmetry [10]. Individuals with freezing of gait have asymmetrical swing times. Turns are inherently asymmetrical, with the outer limb traveling further than the inner limb. As such, baseline gait asymmetries may be more problematic during turning than during straight walking. The asymmetrical nature of turns may contribute to turns being a major trigger for freezing [8]. Though never studied, it may be that individuals with more pronounced gait asymmetry are the ones who have difficulty turning and that turns are most difficult when the limb that normally has the shorter swing time is required to be the outer limb, i.e. the limb that now needs to have a longer swing time. If overcoming baseline asymmetry when turning toward the limb that normally has the longer swing time is problematic, then training to counteract the baseline asymmetry and facilitate turning in this direction could be useful. The rotating treadmill may provide just such a stimulus and further studies are warranted.

Yet another possible mechanism for freezing is difficulty switching between motor tasks [11]. Perhaps turning triggers freezing because the transition from straight walking to a turning pattern is impaired in PD. Multiple studies have demonstrated that subjects with PD have difficulty with internally cued movements, but often respond well to external cues [12]. The treadmill could serve as an external cue for turning. Through practice of externally cued turning, a motor pattern appropriate for turning may become more automatic, facilitating the ease of switching between straight walking and turning. This may be the mechanism of improved turning ability and reduced freezing following rotating treadmill training.

Limitations

This study is limited by the fact that only two subjects were studied, as the bulk of subjects recruited did not have consistent freezing in the lab setting. As such, we did not have sufficient power to run statistical tests. Nonetheless, these preliminary observations are exciting and encouraging. Another limitation of this work is that performance was only assessed immediately following training. Future studies must obviously include larger sample sizes, investigation of retention, and determination of maintenance schedules.

Conclusions

This preliminary investigation suggests that the rotating treadmill may prove to be a beneficial form of training for individuals with advanced PD who have on-period freezing. We hypothesize that training on the rotating treadmill may help to reinforce normal motor patterns for turning, whether it be by helping to standardize step length and reduce the sequence effect, counteracting baseline asymmetries in gait, and/or making turning more automatic and facilitating the voluntary generation of turning patterns. This work is important because it

demonstrates the feasibility of successfully using such a device in PD and lays the groundwork for future work with larger samples.

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References

1. Cumming R, Klineberg R. Fall frequency and characteristics and the risk of hip fractures. *J Am Ger Society* 1994;42:774–8.
2. Melton LJ 3rd, Leibson CL, Achenbach SJ, Bower JH, Maraganore DM, Oberg AL, Rocca WA. Fracture risk after the diagnosis of Parkinson's disease: influence of concomitant dementia. *Mov Disord* 2006;21(9):1361–7. [PubMed: 16703587]
3. Bacon WE. Secular trends in hip fracture occurrence and survival rate: age and sex differences. *J Aging Health* 1996;8:538–53. [PubMed: 10182385]
4. Earhart GM, Hong M. Kinematics of podokinetic after-rotation: similarities to voluntary turning and potential clinical implications. *Brain Res Bull* 2006;70(1):15–21. [PubMed: 16750478]
5. Gordon CR, Fletcher WA, Melvill Jones G, Block EW. Adaptive plasticity in the control of locomotor trajectory. *Exp Brain Res* 1995;102:540–5. [PubMed: 7737400]
6. Hong M, Perlmutter JS, Earhart GM. Podokinetic after-rotation in Parkinson disease. *Brain Res* 2007;12;1128(1):99–106. [PubMed: 17140549]
7. Mathias S, Nayak U, Isaacs B. Balance in elderly patients: the “Get-up and Go” test. *Arch Phys Med Rehab* 1986;67:387–9.
8. Stack EL, Ashburn AM, Jupp KE. Strategies used by people with Parkinson's disease who report difficulty turning. *Parkinsonism Relat Disord* 2006;12:87–92. [PubMed: 16338159]
9. Iansek R, Huxham F, McGinley J. The sequence effect and gait festination in Parkinson disease: contributors to freezing of gait? *Mov Disord* 2006;21(9):1419–24. [PubMed: 16773644]
10. Plotnik M, Giladi N, Balash Y, Peretz C, Hausdorff JM. Is freezing of gait in Parkinson's disease related to asymmetric motor function? *Ann Neurol* 2005;57:656–63. [PubMed: 15852404]
11. Giladi N, McMahon D, Przedborski S, Flaster E, Guillory S, Kostic V, Fahn S. Motor blocks in Parkinson's disease. *Neurology* 1992;42:333–9. [PubMed: 1736161]
12. Siegert RJ, Harper DN, Cameron FB, Abernethy D. Self-initiated versus externally cued reaction times in Parkinson's disease. *J Clin Exp Neuropsychol* 2002;24:146–53. [PubMed: 11992197]

Figure 1.

Illustration of two trials of turning from a subject with PD before (A) and after (B) a single session of rotating treadmill training. Both turns are to the left, the direction of turning trained during the session. EMG records from bilateral vastus lateralis muscles are shown along with vertical position of the calcaneus for each trial. Note the freezing in panel A, marked by asterisks, during which the left foot remains planted and the right heel wavers up and down. The subject's right toe remained on the floor during these freezes. Accompanying EMG activity shows rapid bursts of high amplitude and short duration in both limbs. Following training (B) the subject does not freeze, shows longer EMG bursts of lower peak amplitude with alternation between the limbs, and executes the turn in considerably less time. (C) Bar graph illustrating

group average ($\pm$ SD) coactivation indices for leftward and rightward turns, before and after treadmill training to the left. Note that there was a decreased coactivation for leftward but not for rightward turns following training.

Figure 2.

Bar graph illustrating group average ($\pm$ SD) Timed Up & Go scores for the blocks of turns performed immediately before and after rotating treadmill training. Note that there was a decrease in TUG scores after training for trials where subjects turned left, the direction trained during the session. There was no change in TUG scores for turns to the right.

Table 1

Subject Characteristics

	Subject 1	Subject 2
Age (yrs)	66	60
Gender	M	M
Duration of PD (yrs)	13	17
UPDRS Motor Subscale Score *	30.5	31
UPDRS Gait Score	2	1
Hoehn & Yahr Stage	3	2
Medications	Sinemet, Sinemet CR	Sinemet, Pramipexole, Benztropine

* Determined while on medication