

## Case Reports

# Physical Therapy for a Patient with Essential Tremor and Prolonged Deep Brain Stimulation: A Case Report

Elizabeth A. Ulanowski<sup>1,2\*</sup>, Megan M. Danzl<sup>1,2</sup> & Kara M. Sims<sup>2</sup>

<sup>1</sup> Doctor of Physical Therapy Program, School of Movement and Rehabilitation Sciences, College of Health Professions, Bellarmine University, Louisville, KY, USA, <sup>2</sup> Bellarmine University/Norton Healthcare Neurologic Physical Therapy Residency, Louisville, KY, USA

### Abstract

**Background:** There is a lack of evidence examining the role of physical therapy (PT) to address movement dysfunction for individuals with essential tremor (ET).

**Case Report:** A 61-year-old male with ET and prolonged bilateral deep brain stimulation (DBS) completed 14 sessions of outpatient PT that emphasized balance, functional movements, and proximal stability training with an integration of principles of body awareness training and visual motor coordination. Improvements were noted in all outcome measures.

**Discussion:** This report describes a novel PT approach that offers a promising means of improving functional mobility and balance while decreasing falls risk in patients with ET.

**Keywords:** Essential tremor, deep brain stimulation, body awareness training, visual motor coordination, physical therapy

**Citation:** Ulanowski EA, Danzl MM, Sims KM. Physical therapy for a patient with essential tremor and prolonged deep brain stimulation: a case report. *Tremor Other Hyperkinet Mov.* 2017; 7. doi: 10.7916/D8X92H0G

\*To whom correspondence should be addressed. E-mail: eulanowski@bellarmine.edu

**Editor:** Elan D. Louis, Yale University, USA

**Received:** January 11, 2017 **Accepted:** February 27, 2017 **Published:** March 15, 2017

**Copyright:** © 2017 Ulanowski et al. This is an open-access article distributed under the terms of the Creative Commons Attribution–Noncommercial–No Derivatives License, which permits the user to copy, distribute, and transmit the work provided that the original authors and source are credited; that no commercial use is made of the work; and that the work is not altered or transformed.

**Funding:** None.

**Financial Disclosures:** None.

**Conflict of Interest:** The authors report no conflict of interest.

**Ethics Statement:** This study was reviewed by the authors' institutional ethics committee and was considered exempted from further review.

### Introduction

Essential tremor (ET) is a progressive neurological disease and is considered the most common movement disorder.<sup>1</sup> Depression, anxiety, and age are associated with increased functional disability in ET, regardless of tremor severity.<sup>2</sup> ET is also associated with a wide range of impairments, such as ataxia, postural instability, impaired tandem walking, and decreased gait speed.<sup>1,3–5</sup> Compared with a control group without ET, individuals with ET demonstrate decreased Berg Balance Scale scores, decreased single limb stance times, and increased Timed Up and Go times, which could indicate an increase in the risk of falls.<sup>1</sup> A 2013 review indicates that gait and balance deficits in patients with ET are well documented in the literature.<sup>6</sup>

Typically, individuals with ET will seek medical management to reduce tremor, such as pharmaceutical remedies or deep brain stimulation (DBS). Although DBS can diminish tremor, prolonged bilateral DBS is linked with postural instability and impairments in gait and

balance in individuals with ET.<sup>1,7</sup> There is a paucity of research investigating rehabilitation for individuals with ET and prolonged DBS with these deficits.

The potential impairments, activity limitations, and participation restrictions associated with ET warrants an examination of the role of physical therapy (PT) to address movement dysfunction. The purpose of this case report is to describe the development, implementation, and outcomes of a novel PT plan of care for a patient with ET. Although the individual in this case report has ET and prolonged DBS, the intervention described is broadly applicable to individuals with ET without DBS.

### Case report

A 61-year-old, Caucasian male presented to an outpatient, multi-disciplinary neurological clinic with a diagnosis of ET of at least 9 years. The patient, a high school-educated retired army veteran, lived with his wife and four children in a multi-level home.

Past medical history included depression, headaches, left elbow fracture, tobacco use (one pack per day), and hypertension. Prescribed medications at the time of the examination were Inderal XI (Propranolol) and Cymbalta (Duloxetine). Past pharmacological management was unknown. Past surgical history consisted of a repair of right knee and left shoulder injuries of unknown pathology, hernia repair, and bilateral DBS to the subthalamic nuclei approximately 9 years before the PT examination.

He perceived initial improvements following the DBS. Over time, the tremor returned, his speech worsened, and he experienced increased dizziness and falling, specifically on stairs and when negotiating tight spaces. The patient reported a falls frequency of two falls per week at the time of the examination.

The patient was referred to the clinic by his neurologist, having not had any previous speech, occupational, or physical therapy. His chief complaints to the physical therapist were increased falls, specifically when walking down the stairs, and bilateral upper extremity tremor.

Based on the history and systems review, vestibular dysfunction (e.g., dizziness while driving), cerebellar dysfunction (e.g., loss of balance in tight spaces), and impaired strength were identified as potential factors contributing to the patient's reported deficits. The physical therapist completed an examination to determine specific impairments pertaining to the subjective reports of falls and postural instability (Table 1).

Standardized outcome measures were administered to assess balance, postural stability, and falls risk based on patient presentation and findings during subjective and objective testing. The physical therapist prioritized obtaining information about the risk of falls when selecting appropriate outcome measures and gaining insight about static and dynamic mobility. These included the Berg Balance Scale (BBS),<sup>8</sup> Functional Gait Assessment (FGA),<sup>9</sup> Five-Times-Sit-to-Stand test (5 × STS),<sup>10</sup> and 10-meter walk test (10MWT).<sup>11</sup> Baseline results are in Table 2. The standardized outcome measures indicated a risk of falls and results below normative values.

Additional important examination findings included subjective reports of dizziness from head turns, difficulty with vertical eye gaze, inability to perform tandem gait, a wide base of support, difficulty with stairs, and inability to perform gait with eyes closed. These deficits are consistent with ET and prolonged DBS.

Clinically, individuals with ET can present similarly to individuals with cerebellar diseases.<sup>4,12-14</sup> Interventions that improve postural control, balance, coordination, and functional mobility for individuals with cerebellar diseases are described.<sup>15-18</sup> Given the similar clinical presentations of individuals with ET and cerebellar disorders,<sup>5</sup> interventions designed to improve proximal stability, balance, and coordination with functional movements were selected as primary components of the PT plan of care. Furthermore, principles of body awareness training (BAT) and visual motor coordination (VMC) were applied to the PT interventions and are described in the following intervention section. BAT and VMC were incorporated to enhance the patient's ability to self-reflect throughout therapy and in his home environment.

The patient received 14 individual 60-minute sessions of PT over 8 weeks (Table 3). Over the 8 weeks, the PT plan of care included integration of the principles of BAT and VMC with the training triumvirate (proximal stability, balance, and functional movements) (Figure 1). These three domains of training were addressed in each session and exercises frequently overlapped these domains. An example of this overlap was the design of the exercise of sit to stand transitions: an inherently functional movement with an emphasis on proper mechanics and repetition (functional movement training), reaching the limits of stability (balance training), and engagement of the core (proximal stability training).

The goal of BAT is to enhance a person's awareness of movements and one's body attempting to reach the limits of stability, especially during slow repetitive movement, and reflecting upon performance.<sup>19-21</sup> Although it is indeterminate if individuals with ET experience deficits

**Table 1. Examination Findings**

Examination	Findings
Manual muscle testing	>4/5 for all major muscle groups <sup>34</sup>
Sensation	Light touch testing of upper and lower extremities intact
Finger-to-nose and heel on shin tests	Impaired non-equilibrium coordination <sup>23</sup>
Vestibular	Smooth pursuits, saccades, and the VOR were examined. <sup>23</sup> Difficulty was noted with an inability to vertically track above eye-level formal VOR testing was inconclusive, potentially due to anxiety associated with inducing dizziness through head turns
Functional observations	Poor proximal stability and body awareness with tasks were evident throughout the examination. As examples, he had difficulty with tandem gait and presented with a posterior lean and backward thrusting motion during sit to stand transitions and stair navigation. Difficulty with cervical and trunk disassociation were noted through observation of functional movements

Abbreviation: VOR, Vestibulo-ocular Reflex.

Table 2. Outcome Measure Results

Outcome Measure	Pre-intervention	1 Month	2 Month	Score Interpretation (MDC and MCID)	Cut-off Scores for Risk of Falls
Berg Balance Scale	44/56	53/56	56/56	Exceeded the MDC of 5 points for those with Parkinsonism <sup>27</sup>	45/56 for community-dwelling adults with balance deficits <sup>24</sup>
Functional Gait Assessment	13/30	20/30	25/30	Exceeded the MDC of 6 points for vestibular disorders <sup>25</sup>	15/30 for those with Parkinson's disease <sup>28</sup>
Five-Times-Sit-to-Stand	18 seconds	18.5 seconds	12.9 seconds	Exceeded the MCID of 2.3 seconds for vestibular disorders <sup>26</sup>	16 seconds for those with Parkinson's disease <sup>30</sup>
10 meter walk test (self-selected)	1.13 m/s	1.2 m/s	1.3 m/s	Did not exceed the MDC of 0.18 m/s for those with Parkinsonism <sup>27</sup>	N/A
10 meter walk test (fast speed)	1.6 m/s	Not Tested	1.7 m/s	Did not exceed the MDC of 0.25 m/s for those with Parkinsonism <sup>27</sup>	N/A

Abbreviations: m/s, Meters/Second; MCID, Minimally Clinically Important Difference; MDC, Minimal Detectable Change.

specifically with body awareness, given this patient's presentation of decreased balance and postural stability and the benefits of BAT to address these deficits in another neurological population (stroke), the principles of this approach were trialed.<sup>19-21</sup> The focus during training for this patient included principles of BAT, such as self-reflection during movements and awareness of changing pressures on the soles of his feet.

Proximal stability training involved core strengthening exercises with the inclusion of cues that guided the patient's attention to increasing awareness of his body in space during activities such as weighted trunk rotation. Balance training involved progressively reaching his limits of stability during activities in a standing position such as reactive stepping. Functional movement training involved increasing body awareness during functional movement patterns such as multi directional gait training.

Consistency of interventions across multiple sessions, therapist-guided verbal cues, and adequate time during and after activities for reflection aimed to improve the patient's understanding of his performance and body positioning. The consistency of interventions was particularly helpful to promote increased focus on body awareness and control as he then did not have to devote attention and cognitive load to always learning a new exercise. Toward the end of the plan of care (sessions 9-14), motor and cognitive loads were added to the training as a means to increase complexity and intensity.

Given the influence of visual feedback on movement,<sup>22</sup> VMC was implemented. VMC is the integration of "both visual and motor abilities with the environmental context to accomplish a goal."<sup>23,p.207</sup>

Integrating visual input into motor abilities was a key component to enhance the overall treatment. VMC was used to heighten information about body movements. Altered functional movement patterns, hypothesized because of poor visual integration, were noted in the examination and during subsequent therapy sessions. Given the patient's presentation and the known cerebellar influence on saccade

generation,<sup>18</sup> exercises to heighten vestibulo-ocular reflex (VOR) functioning and saccades were incorporated.

VMC was incorporated into balance and proximal stability training through hand or target tracking. The introduction of VMC into functional movement patterns occurred within realistic and salient activities.

Outcome measures were reassessed during sessions 8 and 14. These time points coincided with the outpatient PT regulations requiring reassessments every 30 days. Currently, there are no established minimal clinically important difference (MCID) or minimal detectable change (MDC) values for individuals with ET for any of the outcome measures in this study. Comparisons of data to the MCID and the MDC, therefore, are based on studies involving individuals with community-dwelling older adults,<sup>24</sup> vestibular disorders,<sup>25,26</sup> or movement disorders.<sup>27-30</sup> Following 8 eight weeks of intervention, the patient demonstrated a clinically meaningful change in the 5 × STS, FGA, and BBS. These results indicate a decrease in the risk of falls. At the time of discharge, the patient reported one fall since the PT evaluation, an improvement from the pre-PT frequency of two falls/week.

## Discussion

There is a paucity of research describing the effectiveness of rehabilitation interventions for individuals with ET and limited evidence examining PT for those with prolonged DBS in those with ET. This case report describes a novel PT approach that emphasized balance, functional movement, and proximal stability training with an integration of principles of BAT and VMC for a 61-year-old patient diagnosed with ET who underwent bilateral DBS 9 years prior. His presentation was consistent with characteristics of ET<sup>3,4</sup> and prolonged DBS.<sup>29</sup> In addition, there were similarities of his presentation to those with cerebellar diseases.<sup>1,17,18,31-33</sup>

Table 3. Intervention Progression

Treatment Session No.	Gait Training	Functional Training	Balance Training	Strengthening	Miscellaneous
1	With a treadmill with verbal cues to increase heel strike, increase base of support, and for foot clearance	Sit to stand training <sup>1</sup>	Multidirectional stepping	Scapular stabilization exercises in supine	Vestibulo-ocular reflex exercises ( $\times 1 / \times 2$ ) <sup>1</sup>
2	With a treadmill with verbal cues to increase base of support, to increase arm swing, to clear the foot	Sit to stand training	Multidirectional stepping with verbal cues: for direction change and to colored dots on floor	Scapular stabilization exercises in supine	
3	With a treadmill with verbal cues to increase base of support, to increase arm swing, to clear the foot		Single limb stance with VMC (eyes open and eyes closed; on foam)	Discontinued scapular stabilization exercises due to lifting restriction; Four-way bilateral hip strengthening with resistance <sup>1</sup>	
4			Single limb stance on foam with trunk rotation	Four-way bilateral hip strengthening with resistance	Upright stationary bicycle with verbal cues for upright posture in an unsupported position Stepping lunges to raised steps with simultaneous trunk rotation
5	Overground <sup>1</sup> with verbal cues for intermittent changes in direction (forward, backward, right, left)	Stepping over obstacles with changes of speeds		Four-way bilateral hip strengthening with resistance	
6	Overground	Gait with obstacle training: stepping over and around objects, outdoor training, hills, ramps, and stairs with changing speeds	Single limb stance with VMC (eyes open and eyes closed; on foam; trunk rotation)	Weighted trunk rotation	
7	With a treadmill with incline with verbal cues for upright posture		Single limb stance on foam with addition of head turns to integrate visual exercises	Squat training with upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand	
8	With a treadmill with incline with verbal cues for upright posture		Single limb stance on foam with addition of head turns and vestibulo-ocular reflex exercises	Squat training with upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand	Outcome measures assessed per outpatient rehabilitation regulations of every 30-day re-assessment

Table 3. Continued

Treatment Session No.	Gait Training	Functional Training	Balance Training	Strengthening	Miscellaneous
9	Overground with resistance bands with verbal cues for upright posture and controlled movements	Stair training with the addition of complex motor tasks; verbal cues for body awareness and controlled movements	Gait and balance training through obstacle course training incorporating single limb stance, cross stepping, reactive stepping, changing speeds, and adding complex motor and cognitive tasks	Upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand while in quadruped and tall kneeling	Upright stationary bicycle with cues for upright posture
10	Overground with resistance bands with verbal cues for upright posture and controlled movements	Stair training with the addition of complex motor tasks; verbal cues for body awareness and controlled movements	Gait and balance training through obstacle course training incorporating single limb stance, cross stepping, reactive stepping, changing speeds, and adding complex motor and cognitive tasks Static balance training that included visual complexity (background changes, head turns, eyes open and eyes closed)	Upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand while in quadruped and tall kneeling	
11	With the treadmill, retro-ambulation with verbal cues for “toe-heel” and leaning forward		Gait and balance training through obstacle course training incorporating single limb stance, cross stepping, reactive stepping, changing speeds, and adding complex motor and cognitive tasks Static balance training that included visual complexity (background changes, head turns, eyes open and eyes closed)	Upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand while in quadruped and tall kneeling	
12	With the treadmill, retro-ambulation with verbal cues for “toe-heel” and leaning forward		Gait and balance training through obstacle course training incorporating single limb stance, cross stepping, reactive stepping, changing speeds, and adding complex motor and cognitive tasks Static balance training that included visual complexity (background changes, head turns, eyes open and eyes closed)	Upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand while in quadruped and tall kneeling	

Table 3. Continued

Treatment Session No.	Gait Training	Functional Training	Balance Training	Strengthening	Miscellaneous
13	With the treadmill, retro-ambulation with verbal cues for "toe-heel" and leaning forward		Gait and balance training through obstacle course training incorporating single limb stance, cross stepping, reactive stepping, changing speeds, and adding complex motor and cognitive tasks  Static balance training that included visual complexity (background changes, head turns, eyes open and eyes closed)	Upper extremity proprioceptive neuromuscular facilitation patterns (D1/D2) including visual tracking of the hand while in quadruped and tall kneeling	
14					Outcome measure assessments for preparation of discharge from therapy Final patient education Final home program recommendations

Abbreviation: VMC, Visual Motor Coordination.  
 †Added to the patient's home exercise program.

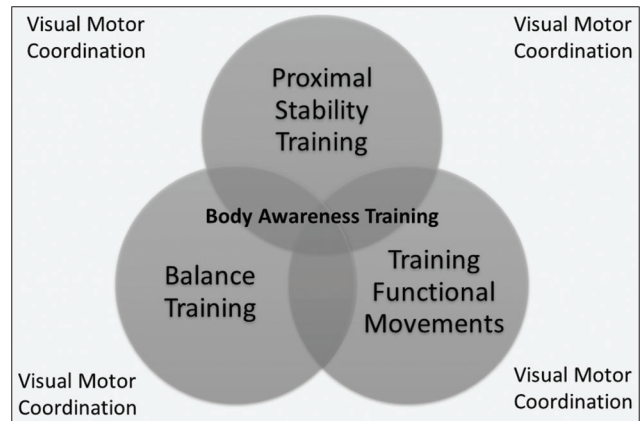


Figure 1. **Conceptual Model of the Physical Therapy Training.** The plan of care that addressed proximal stability, balance, and functional movements integrated principles of body awareness training and visual motor coordination.

The outcome measures encompassed constructs reflective of the interventions that promoted body awareness and visual integration during balance, complex movements, and functional patterns. The patient demonstrated clinically significant improvements in outcome measures of balance and functional mobility as well as a decreased fall risk, although it is noted that the measures of clinical significance and cut-off scores for fall risk were in populations other than ET. Future research is needed to establish psychometric properties of these outcome measures for individuals with ET. Improvements in gait speed were demonstrated although clinical significance was not achieved. Gait training was incorporated, but the emphasis was on body awareness, VMC, and balance during gait, not solely increasing gait speed.

Attributing his improvements to this specific PT plan of care is indeterminate given the retrospective case report design. Given the patient's level of inactivity prior to therapy, there is the potential that improvements were due to participation in physical activity, regardless of type. In the future, utilization of an A-B-A design would help determine if improvements are attributable to the PT intervention and if those effects endure. Delaying intervention for active fallers to obtain a baseline, however, may warrant further discussion regarding the ethical implications. Larger scale trials with more rigorous research designs are needed to examine the effects of PT for those with ET and the value of integrating BAT and VMC with training.

This case report provides a description of interventions used including BAT and VMC for clinicians who would like to trial this approach for individuals with similar presentations. This case report supports referrals by physicians to neurologic physical therapists for evaluation and treatment of individuals with ET to improve balance and functional movements and decrease falls risk.

**Acknowledgments**

The authors wish to acknowledge the support of The Bellarmine University and Norton Healthcare Neurologic Residency Mentor, Erin Weigle, PT, DPT, NCS, for her guidance during patient care. We would also like to thank the patient and his cooperation with this work.

## References

1. Earhart GM, Clark BR, Tabbal SD, et al. Gait and balance in essential tremor: variable effects of bilateral thalamic stimulation. *Mov Disord* 2009;24:386–391. doi: 10.1002/mds.22356
2. Thanvi B, Lo N, Robinson T. Essential tremor—the most common movement disorder in older people. *Age Ageing* 2006;35:344–349. doi: 10.1093/ageing/afj072
3. Benito-Leon J, Louis ED. Essential tremor: emerging views of a common disorder. *Nat Clin Pract Neurol* 2006;2:666–678. doi: 10.1038/ncpneu0347
4. Bain PG, Findley LJ, Thompson PD, et al. A study of hereditary essential tremor. *Brain* 1994;117:805–824. doi: 10.1093/brain/117.4.805
5. Stolze H, Petersen G, Raethjen J, et al. The gait disorder of advanced essential tremor. *Brain* 2001;124:2278–2286. doi: 10.1093/brain/124.11.2278
6. Arkadir D, Louis ED. The balance and gait disorder of essential tremor: what does this mean for patients? *Ther Adv Neurol Disord* 2013;6:229–236. doi: 10.1177/1756285612471415
7. Pahwa R, Lyons KE, Wilkinson SB, et al. Long-term evaluation of deep brain stimulation of the thalamus. *J Neurosurg* 2006;104:506–512. doi: 10.3171/jns.2006.104.4.506
8. Berg KO, Wood-Dauphinee SL, Williams JI, et al. Measuring balance in the elderly: validation of an instrument. *Can J Public Health* 1992;83 Suppl 2: S7–11.
9. Wrisley DM, Marchetti GF, Kuharsky DK, et al. Reliability, internal consistency, and validity of data obtained with the functional gait assessment. *Phys Ther* 2004;84:906–918.
10. Whitney SL, Wrisley DM, Marchetti GF, et al. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test. *Phys Ther* 2005;85:1034–1045.
11. Tyson S, Connell L. The psychometric properties and clinical utility of measures of walking and mobility in neurological conditions: a systematic review. *Clin Rehabil* 2009;23:1018–1033. doi: 10.1177/0269215509339004
12. Singer C, Sanchez-Ramos J, Weiner WJ. Gait abnormality in essential tremor. *Mov Disord* 1994;9:193–196. doi: 10.1002/mds.870090212
13. Gironell A, Kulisevsky J. Diagnosis and management of essential tremor and dystonic tremor. *Ther Adv Neurol Disord* 2009;2:215–222. doi: 10.1177/1756285609104791
14. Lundy-Ekman L. *Neuroscience: fundamentals for rehabilitation*. 4th ed. St. Louis, MO: Elsevier; 2013.
15. Bilodeau M, Keen DA, Sweeney PJ, et al. Strength training can improve steadiness in persons with essential tremor. *Muscle Nerve* 2000;23:771–778. doi: 10.1002/(SICI)1097-4598(200005)23:5<771::AID-MUS15>3.0.CO;2-9
16. Ilg W, Synofzik M, Brotz D, et al. Intensive coordinative training improves motor performance in degenerative cerebellar disease. *Neurology* 2009;73:1823–1830. doi: 10.1212/WNL.0b013e3181c33adf
17. Miyai I, Ito M, Hattori N, et al. Cerebellar ataxia rehabilitation trial in degenerative cerebellar diseases. *Neurorehabil Neural Repair* 2012;26:515–522. doi: 10.1177/1545968311425918
18. Quinet J, Goffart L. Cerebellar control of saccade dynamics: contribution of the fastigial oculomotor region. *J Neurophysiol* 2015;113:3323–3336. doi: 10.1152/jn.01021.2014
19. Bang DH, Cho HS. Effect of body awareness training on balance and walking ability in chronic stroke patients: a randomized controlled trial. *J Phys Ther Sci* 2016;28:198–201. doi: 10.1589/jpts.2016.198
20. Lindvall MA, Forsberg A. Body awareness therapy in persons with stroke: a pilot randomized controlled trial. *Clin Rehabil* 2014;28:1180–1188. doi: 10.1177/0269215514527994
21. Lindvall MA, Anderzen Carlsson A, Forsberg A. Basic body awareness therapy for patients with stroke: experiences among participating patients and physiotherapists. *J Bodyw Mov Ther* 2016;20:83–89. doi: 10.1016/j.jbmt.2015.06.004
22. Parmar PN, Huang FC, Patton JL. Simultaneous coordinate representations are influenced by visual feedback in a motor learning task. *Conf Proc IEEE Eng Med Biol Soc* 2011;2011:6762–6768. doi: 10.1109/IEMBS.2011.6091668
23. O’Sullivan SB, Schmitz TJ, Fulk GD. *Physical rehabilitation*. 6th ed. Philadelphia: F.A. Davis Co.; 2014.
24. Marchetti GF, Lin CC, Alghadir A, et al. Responsiveness and minimal detectable change of the dynamic gait index and functional gait index in persons with balance and vestibular disorders. *J Neurol Phys Ther* 2014;38:119–124. doi: 10.1097/NPT.000000000000015
25. Meretta BM, Whitney SL, Marchetti GF, et al. The five times sit to stand test: responsiveness to change and concurrent validity in adults undergoing vestibular rehabilitation. *J Vestib Res* 2006;16:233–243.
26. Steffen T, Seney M. Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism. *Phys Ther* 2008;88:733–746. doi: 10.2522/ptj.20070214
27. St George RJ, Nutt JG, Burchiel KJ, et al. A meta-regression of the long-term effects of deep brain stimulation on balance and gait in PD. *Neurology* 2010;75:1292–1299. doi: 10.1212/WNL.0b013e3181f61329
28. Topka H, Konczak J, Dichgans J. Coordination of multi-joint arm movements in cerebellar ataxia: analysis of hand and angular kinematics. *Exp Brain Res* 1998;119:483–492. doi: 10.1007/s002210050364
29. Deuschl G, Wenzelburger R, Loffler K, et al. Essential tremor and cerebellar dysfunction: clinical and kinematic analysis of intention tremor. *Brain* 2000;123:1568–1580. doi: 10.1093/brain/123.8.1568
30. Nawrot M, Rizzo M. Motion perception deficits from midline cerebellar lesions in human. *Vision Res* 1995;35:723–731. doi: 10.1016/0042-6989(94)00168-L
31. Kendall FP. *Muscles: testing and function with posture and pain*. 5th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2005.
32. Kornetti DL, Fritz SL, Chiu YP, et al. Rating scale analysis of the Berg Balance Scale. *Arch Phys Med Rehabil* 2004;85:1128–1135. doi: 10.1016/j.apmr.2003.11.019
33. Leddy AL, Crouner BE, Earhart GM. Functional gait assessment and balance evaluation system test: reliability, validity, sensitivity, and specificity for identifying individuals with Parkinson disease who fall. *Phys Ther* 2011;91:102–113. doi: 10.2522/ptj.20100113
34. Duncan RP, Leddy AL, Earhart GM. Five times sit-to-stand test performance in Parkinson’s disease. *Arch Phys Med Rehabil* 2011;92:1436–1431. doi: 10.1016/j.apmr.2011.04.008