

Reduced Automaticity of Walking

Boston University Sargent College
of Health & Rehabilitation Sciences

The diagram illustrates the neural pathways for walking in two conditions: Healthy (A) and Parkinson Disease (B). Both conditions show a similar flow of information from Attentional Networks to the Motor Cortex, leading to Daily Motor Behaviors. In the Healthy condition (A), the Sensorimotor Striatum is active and receives input from the Associative Striatum. In the Parkinson Disease condition (B), the Sensorimotor Striatum is shown with a red 'X' and a red lightning bolt, indicating a disruption or reduction in its function, which leads to reduced automaticity of walking.

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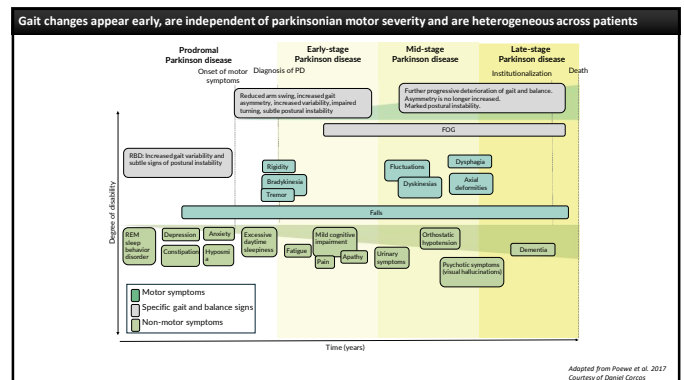
graph TD
    subgraph A [Healthy]
        AN1[Attentional Networks] --> AS1[Associative Striatum]
        AS1 --> MC1[Motor Cortex]
        AN1 --> MC1
        AS1 --> SS1[Sensorimotor Striatum]
        SS1 --> MC1
        MC1 --> DB1[Daily Motor Behaviors]
    end
    subgraph B [Parkinson Disease]
        AN2[Attentional Networks] --> AS2[Associative Striatum]
        AS2 --> MC2[Motor Cortex]
        AN2 --> MC2
        AS2 --> SS2[Sensorimotor Striatum]
        SS2 --> MC2
        MC2 --> DB2[Daily Motor Behaviors]
    end

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- Going beyond tremor, rigidity and bradykinesia.....
- Dopamine depletion to the sensorimotor striatum leads to reduced automaticity of daily motor tasks.
- Attentional networks take over via the associative striatum (caudate nucleus)

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Wu & Hukker 2015



Parameter	Early/prodromal finding	PD specificity
Gait speed	Reduced	Low (nonspecific)
Step/stride length	Shortened (later in prodromal course)	Moderate
Arm-swing amplitude	Reduced, asymmetric	High
Interlimb asymmetry	Increased	High
Cadence	Increased	Moderate
Double-support time	Prolonged	Moderate
Step time / variability	Increased (earliest temporal marker)	High
Dual-task cost	Increased (~18.7% in H&Y I-II)	High



A photograph showing a person from behind, walking away from the camera down a hallway. The person is wearing a light green short-sleeved shirt and light-colored shorts. The hallway has blue carpeting and white walls. This image illustrates the concept of gait impairment, which is a key feature of Parkinson's disease.

Mirreman et al., Lancet Neurology 2019;
 Kim SW et al., Neurology 2020;
 Chartier-Linlin et al., Neurology 2015



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JNPT
JOURNAL OF NEUROLOGICAL
PHYSICAL THERAPY
RESEARCH ARTICLES

Capturing Ambulatory Activity Decline in Parkinson's Disease

Cavanagh, James E. PT, PhD, NCS, ELS, Terry D. PT, PhD, NCS, ELS, Earhart, Gertsenso M. PT, PhD, FORD, Matthew P. PT, PhD, Foreman, K. BS PT, PhD, Dibiase, Leland E. PT, PhD, ALC

Author Information@

Journal of Neurological Physical Therapy 34(2) p 51-57, June 2012. | DOI: 10.5937/JNPT.090734302445476



Physical Therapy
Journal of Neurological Physical Therapy

* Phys Ther. 2013 Apr;93(8):1142-1150. doi: 10.2522/pt.2012.0498

Toward Understanding Ambulatory Activity Decline in Parkinson Disease

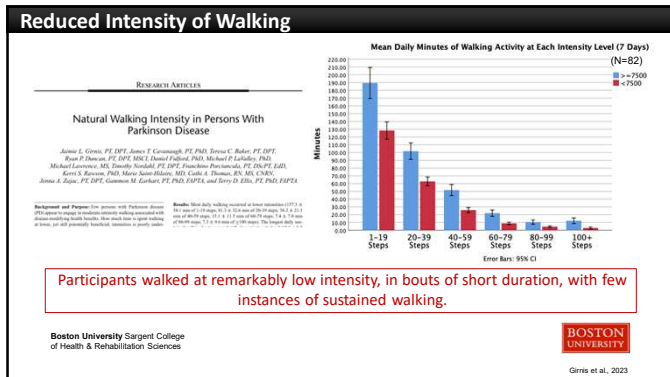
James T. Cavanagh^{1,2*}, Terry D. Ellis³, Gertsenso M. Earhart⁴, Matthew P. Ford⁵, K. B. Foreman⁶, Leland E. Dibiase⁶

Changes in Walking Performance in Persons with Parkinson Disease over 1-year

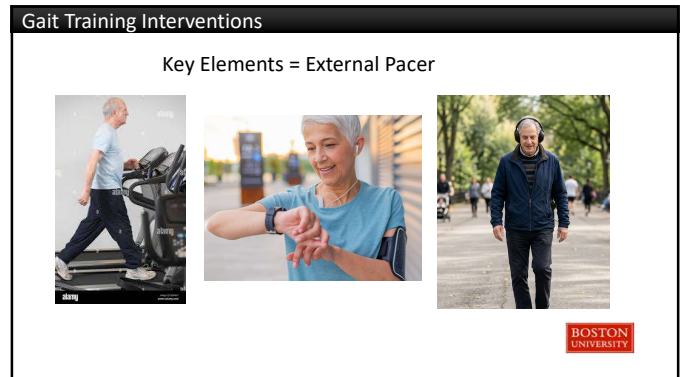
Variable	% change / effect size
Steps*	-12 / 0.28
Moderate intensity minutes*	-40 / 0.30

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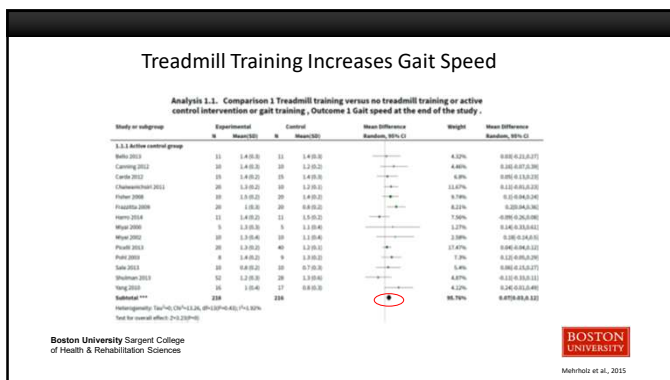
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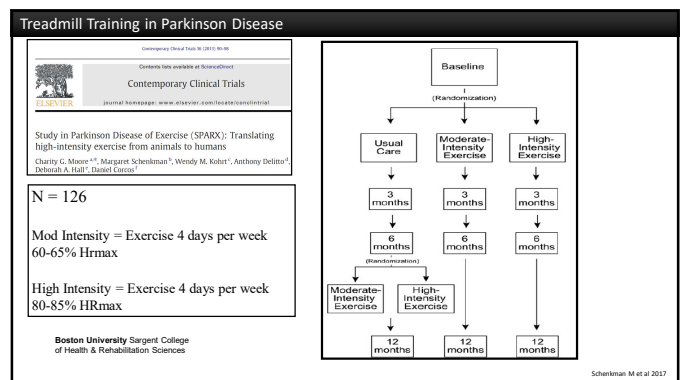
7



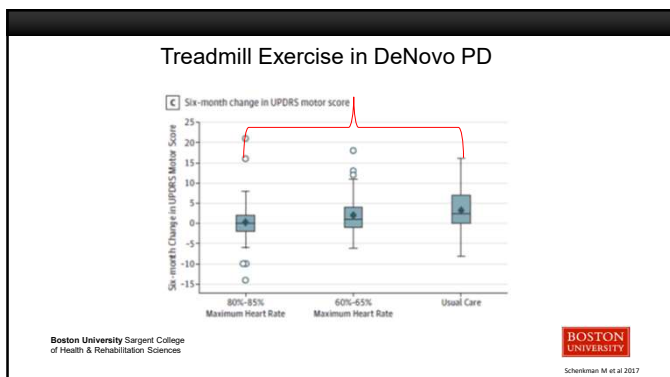
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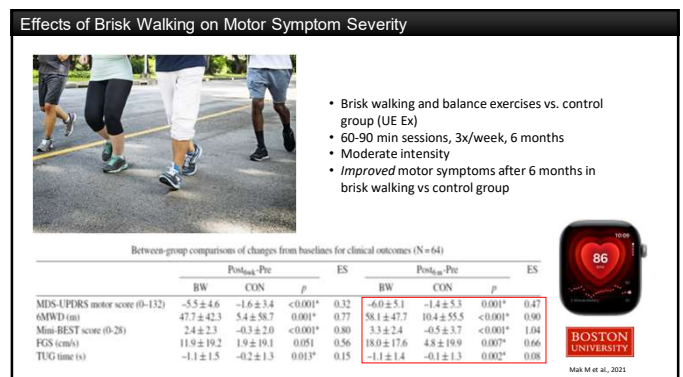
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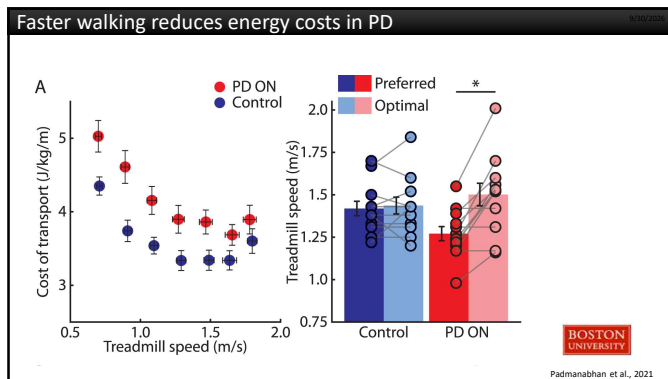
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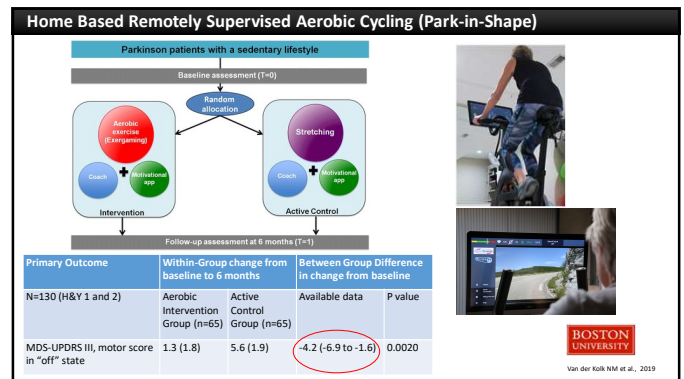
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Specificity of Training Effect

	Baseline		6 months		Within group change from baseline after 6 months		Between group difference in change from baseline	
	Aerobic intervention group (n=62)	Active control group (n=65)	Aerobic intervention group (n=62)	Active control group (n=65)	Aerobic intervention group (n=62)	Active control group (n=65)	Available data	p-value
Number of falls	43 (0.9)	30 (0.9)	23 (0.9)	45 (0.9)	-21 (0.7)	-07 (1.8)	-13 (41--12.8 to 0.1)	0.76
6-min walk test, m	459.4 (18.2)	486.4 (18.2)	530.6 (12.7)	493.8 (12.7)	-13.3 (11.8)	-15.6 (12.2)	43 (8.8--13.0 to 21.6)	0.62
Timed Up and Go test, s	8.3 (0.5)	8.7 (0.5)	8.2 (0.5)	8.6 (0.5)	0.5 (0.4)	0.7 (0.4)	-0.2 (0.3--0.7 to 0.3)	0.49
Mini-Balance Evaluation Systems Test	24.3 (0.6)	24.2 (0.6)	24.4 (0.6)	24.5 (0.6)	0.5 (0.5)	0.5 (0.5)	-0.03 (0.4--0.7 to 0.7)	0.94

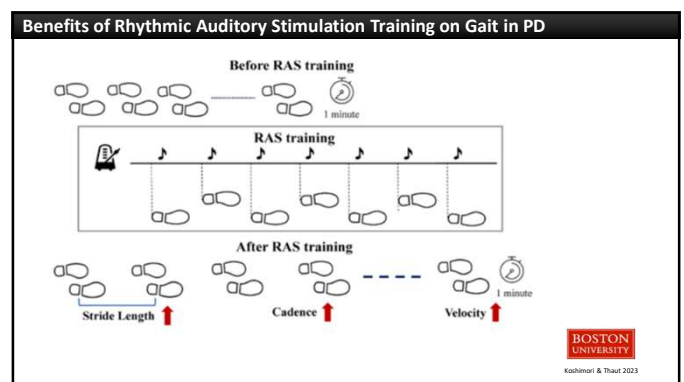
- No improvements in gait or balance metrics following 6 months of cycling
- Consistent improvements in gait and balance metrics following 6 months of walking related exercise suggesting a specificity of training effect

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Van der Kolk NM, NM, 2019

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Beat Move: Synchronized Music Rehabilitation in real-world

N = 25 with PD
5x/wk x 30 mins for 1 month
Real-time, synchronized, cued music



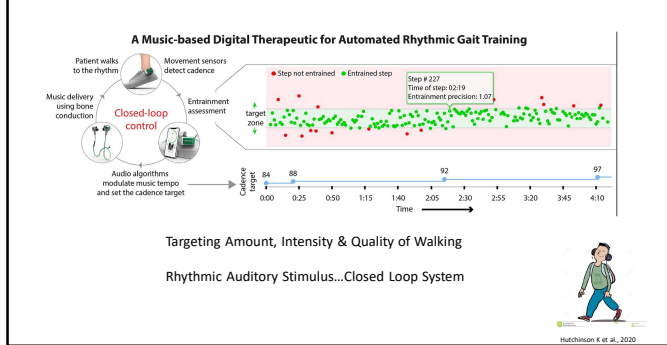
	Effect of rehabilitation program with BeatMove			
All minutes	First three sessions	Last three sessions		
Distance (m)	2404.56 ± 400.14	2502.79 ± 415.46	0.03	96.23 ± 212.52
Speed (m/s)	1.41 ± 0.23	1.47 ± 0.25	0.03	0.06 ± 0.13
Step length (m)	0.73 ± 0.12	0.75 ± 0.12	0.04	0.03 ± 0.06
Cadence (steps/min)	118.82 ± 9.38	120.16 ± 10.37	0.34	1.34 ± 6.81
Silent evaluation				
6-min walk test	Before	After		
Distance (m)	438.29 ± 76.41	462.94 ± 65.31	0.002	24.65 ± 31.98
Speed (m/s)	1.22 ± 0.21	1.29 ± 0.18	0.002	0.07 ± 0.09
Stride length (m)	1.27 ± 0.14	1.30 ± 0.16	0.04	0.03 ± 0.05
Cadence (steps/min)	116.52 ± 12.14	120.42 ± 9.95	0.01	3.91 ± 6.61

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Bourdon, A et al., 2025

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Closed Loop Music-Based Digital Neurotherapeutic



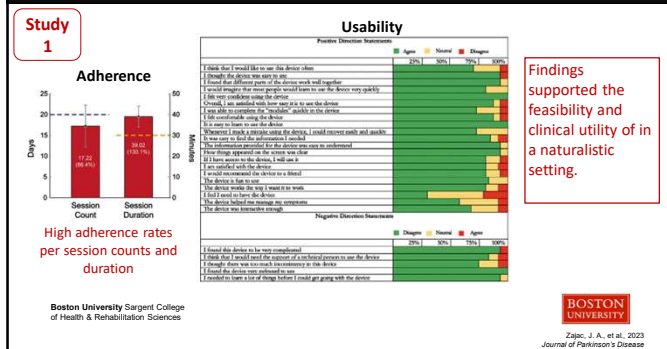
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Alternative Gait Circuitry: Closed-loop rhythmic auditory stimulus system



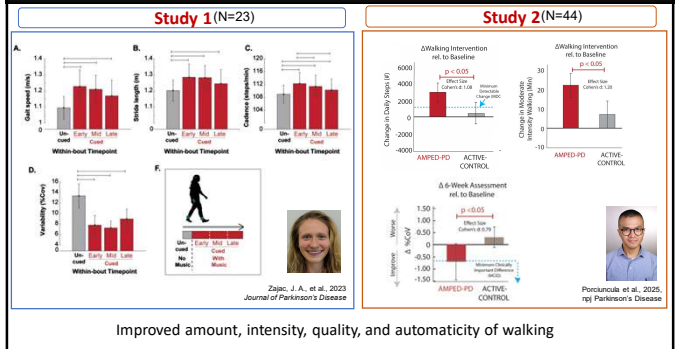
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Alternative Gait Circuitry: Closed-loop rhythmic auditory stimulus system



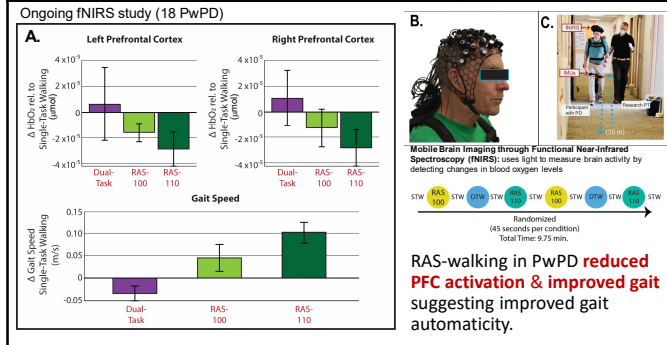
21

Alternative Gait Circuitry: Closed-loop rhythmic auditory stimulus system



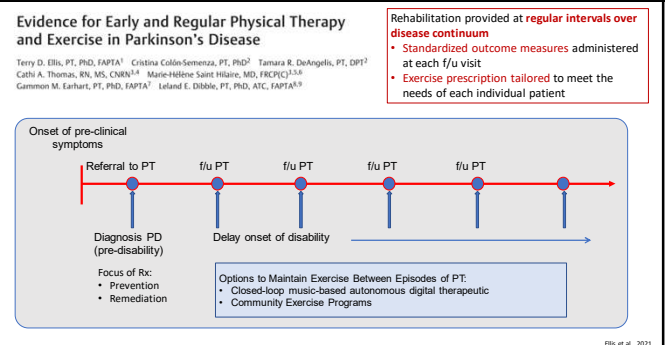
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Alternative Gait Circuitry: Prefrontal brain activation during RAS-aided walking



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Secondary Prevention Model of Care



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Is a Secondary Prevention Model Supported by the Evidence?

JAMA Neurology | Original Investigation

Effect of High-Intensity Treadmill Exercise on Motor Symptoms in Patients With De Novo Parkinson Disease
A Phase 2 Randomized Clinical Trial

Schenkman M et al. JAMA Neurol. 2018

YES!

Effectiveness of home-based and remotely supervised aerobic exercise in Parkinson's disease: a double-blind, randomised controlled trial

van der Kolk NM et al. Lancet Neurol. 2019

Six-Month Community-Based Brisk Walking and Balance Exercise Alleviates Motor Symptoms and Promotes Functions in People with Parkinson's Disease: A Randomized Controlled Trial

Mak MKY, Wong-Yu SK. J Parkinsons Dis. 2021

A Two-Year Randomized Controlled Trial of Progressive Resistance Exercise for Parkinson's Disease

Corcos DM et al. Mov Disord. 2013

Long-term Effect of Regular Physical Activity and Exercise Habits in Patients With Early Parkinson Disease

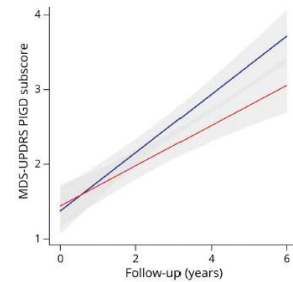
Toukita K et al., Neurology 2022



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Higher and regular physical activity is associated with better mobility over time

— Lower daily physical activity levels (n = 86)
— Higher daily physical activity levels (n = 86)



Higher regular moderate to vigorous physical activity was associated with a slower decline in postural stability and gait function

Toukita K, 2022

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Real-world gait changes precede Parkinson's disease diagnosis in a population-scale UK biobank cohort

- **Ecological, real-world walking behavior measured years before clinical diagnosis**
- **Cohort:** 73,413 UK Biobank participants
- **Wearable assessment:** Wrist-worn accelerometer worn for 7 days
- **Digital gait measures:** 17 real-world gait and walking biomarkers derived using the Watch Walk algorithm
- **PD ascertainment:** Linked electronic health records; participants followed for up to 10 years
- **Incident PD:** 314 participants developed PD after accelerometry; analyzed by time to diagnosis: 1–40, 41–60, 61–80, and 81–119 months

Boston University College of Health & Rehabilitation Sciences: Sargent College
Department of Physical Therapy & Athletic Training

Pellicori et al., Journal of Neural Transmission, 2020

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Real-world gait changes precede Parkinson disease diagnosis by years

Group	Steps/day, mean (SD)	Difference vs. controls	Effect size (d)
Healthy controls	6,370 (2,656)	—	—
Prevalent PD	4,212 (2,622)	−2,158	−0.817*
Incident PD: 1–40 mo	4,043 (2,017)	−2,327	−0.986*
Incident PD: 41–60 mo	4,719 (2,555)	−1,651	−0.633*
Incident PD: 61–80 mo	5,397 (2,918)	−973	−0.348
Incident PD: 81–119 mo	5,585 (2,173)	−785	−0.323

↓ **Daily steps**
~800–2,300 fewer steps/day before diagnosis
 Largest difference: ~2,327 steps/day within 40 months of diagnosis
 Potential signal of reduced real-world mobility in the prodromal period

Pellicori et al., Journal of Neural Transmission, 2020

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Does Walking Capacity tell the Whole Story?

Parkinsonism and Related Disorders 105 (2022) 125–127

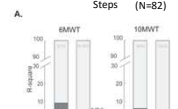
Contents lists available at ScienceDirect
Parkinsonism and Related Disorders
journal homepage: www.elsevier.com/locate/prdis

Does clinically measured walking capacity contribute to real-world walking performance in Parkinson's disease?

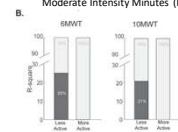
Jenna A. Zajac^{a,*}, James T. Cavanaugh^b, Teresa Baker^c, Ryan P. Duncan^{a,f,g}, Daniel Fuld^a,
Jaime Giris^a, Michael LaValley^a, Timothy Nordahl^a, Franchino Porciuncula^a,
Kerri S. Rawson^a, Marie Saint-Hilaire^a, Cathi A. Thomas^a, Gammon M. Earhart^{a,g,h},
Terry D. Ellis^a

Walking capacity explained a relatively small portion of the variance in real-world walking performance.

Contribution of Walking Capacity to Daily Steps (N=82)



Contribution of Walking Capacity to Moderate Intensity Minutes (N=82)



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RESEARCH ARTICLES

Improvement in the Capacity for Activity Versus Improvement in Performance of Activity in Daily Life During Outpatient Rehabilitation

Catherine E. Lang, PT, PhD, FAPTA, Carey L. Holleran, PT, DPT, DHS, Michael J. Strube, PhD,
Terry D. Ellis, PT, PhD, FAPTA, Cathi A. Thomas, DPT, Meghan Fahy, PT, DPT,
Timara R. DuAngelis, PT, DPT, Timothy J. Nordahl, PT, DPT, Darcy S. Reisman, PT, PhD, FAPTA,
Gammon M. Earhart, PT, PhD, FAPTA, Kerri R. Lohse, PhD, and Margherita D. Bland, PT, DPT, MSCI

PD Walking (n=57)	Performance +	Performance -
Capacity +	9%	47%
Capacity -	2%	42%

Discrepancy between capacity and performance

Capacity = describes what an individual can do in a standardized environment.
Performance = describes what an individual does in their current environment.



Lang et al., JNPT 2022

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Physical Therapy
Journal of the American Physical Therapy Association

PTJ Online First

Barriers to Exercise in People With Parkinson Disease
Terry Ellis, Jennifer K. Bradshaw, Tamara B. Dwagonski, Lisa L. Brown, James T. Conneough, Shannon M. Carlson, Matthew P. Ford, R. Bo Foreman and Leonard E. Glaser
PHYS THER. Published online January 3, 2013
doi: 10.2522/ptj.20120279

Physical Therapy
Journal of the American Physical Therapy Association

PTJ

Factors Associated With Exercise Behavior in People With Parkinson Disease
Tara Ellis, James T. Conneough, Shannon M. Carlson, Matthew P. Ford, R. Bo Foreman, Lisa Friedman, Jennifer K. Bradshaw and Leonard E. Glaser
PHYS THER. 2013; 93:1830-1840
Originally published online October 14, 2011
doi: 10.2522/ptj.20110360

**Boston University College of Health & Rehabilitation Sciences; Sargent College
Department of Physical Therapy & Athletic Training**

Most Common Barriers to Exercise in Persons with PD:

- Low Self-Efficacy
- Low Outcome Expectation
- Fear of Falling

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Promoting Behavioral Change

Common behavioral change theories are cognitive:

- Theory of Planned Behavior
- Social-Cognitive Theory
- Self-Determination Theory

Cognitive theories assume rationality, some level of motivation and ability to engage in goal-oriented behavior / action planning.

Building Self-Efficacy through Mastery

GOAL SETTING

- 1 Specific
- 2 Measurable
- 3 Achievable
- 4 Realistic
- 5 Timely

Action Planning

Who? What? When? Where?

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Building Habits

Define conditions under which an individual is likely to repeat the desired behavior (e.g., PA/exercise)

- **Habits are automatized behavioral patterns that get instigated by context dependent triggers**

Processes can be used to achieve these conditions:

- **Reduce friction** in the environment (i.e., the ease/difficulty of performing the action)
- Providing **"nudges"** as a means of encouraging or giving direction towards a certain desired behavior without instructing or mandating a person to do something.
- Increasing **enjoyability** (i.e., the pride, positive affect, or goal congruence of an action)

Goal: Build habit specific self-efficacy

DAILY ROUTINE

Mikman R. 2021, September 2021, November 2015

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International Consensus Statement for Rehabilitation in PD

D. Timing and settings for rehabilitative services

D1. Rehabilitative services should be implemented across all stages of disease and

D2. Early referral to rehabilitative services should be recommended to individuals as soon as they are diagnosed with PD and should continue with regular modifications throughout disease progression as needed.

D3. Rehabilitation providers should conduct rehabilitation assessments at first presentation of PD to establish baseline status, with input from the multidisciplinary

D4. Rehabilitation providers should conduct serial and follow up rehabilitation assessments at regular intervals throughout disease progression (e.g., approximately every 6 months,

D5. Rehabilitative services can be provided in a variety of settings including: outpatient therapy locations, day rehabilitation programs, inpatient hospital programs, community-

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Boston University Center for Neurorehabilitation Team

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PF1 [@Ellis, Theresa] I realize we do not have Regina and Meryem for the fnirs work... do we want to include?

Porciuncula, Franchino, 2026-01-30T19:31:48.253