



## **Gait Analysis in Clinical Practice: Phenomenology, Differential Diagnosis, and Application**

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# Key References

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- Nonnekes J, Růžička E, Serranová T, Reich SG, Bloem BR, Hallett M. **Functional gait disorders: A sign-based approach.** Neurology. 2020;94(24):1093-9.
- Nonnekes J, Goselink RJM, Růžička E, Fasano A, Nutt JG, Bloem BR. **Neurological disorders of gait, balance and posture: a sign-based approach.** Nat Rev Neurol. 2018;14(3):183-9.
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- Nutt JG. **Higher-level gait disorders: an open frontier.** Mov Disord. 2013;28(11):1560-5.
- Snijders AH, van de Warrenburg BP, Giladi N, Bloem BR. **Neurological gait disorders in elderly people: clinical approach and classification.** Lancet Neurol. 2007;6(1):63-74.

# **Gait Disorder: Introduction**

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# Gait disorder: Introduction

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- Gait disorder is **very common** and affects **quality-of-life in the elderly**.
- Prevalence: **30%** in 60-97 years old population, **>60%** in over 80 years old population
- Cause: **75%** neurological causes / **55%** non-neurological causes
  - **29%** both neurological and non-neurological causes
- Impact: increase **fall** risk, decrease general condition and **life expectancy**

# Elements for gait examination

- **Spatiotemporal features**

- Velocity
- Cadence
- Step length
- Asymmetry
- Step width
- Variability

- **Lower extremity features**

- Weakness, pain, stiffness, dyskinesia

- **Additional features**

- Upper extremities features
- Posture
- Other movements

- **Episodic features**

- Freezing of gait (FOG)



# Proposed classifications and pitfalls

Classification	Examples	Pitfalls	Classification	Examples	Pitfalls
Hierarchical	<p>Lower level</p> <p>Peripheral skeleto muscular problems (arthritic, myopathic, and peripheral neuropathic gait)</p> <p>Peripheral sensory problems (sensory/vestibular/visual ataxic gait)</p> <p>Intermediate level</p> <p>Hemiplegic gait</p> <p>Paraplegic gait</p> <p>Cerebellar ataxic gait</p> <p>Parkinsonian gait</p> <p>Choreic gait</p> <p>Dystonic gait</p> <p>Higher level (higher-level gait disorder)</p>	<p>Overlap in symptoms between different levels (eg, Parkinson disease patients might also display features of higher-level gait disorder)</p> <p>Higher-level gait disorder entity is often abused with confusing nomenclature</p> <p>Higher-level gait disorder subtypes are difficult to recognize in clinical practice</p>	<p>Anatomic</p> <p>Etiologic</p> <p>Phenomenologic</p>	<p>Frontal, cerebellar, etc</p> <p>Vascular, neurodegenerative, etc</p> <p>Antalgic</p> <p>Paretic/hypotonic</p> <p>Spastic</p> <p>Vestibular</p> <p>Sensory ataxic</p> <p>Cerebellar ataxic</p> <p>Dyskinetic</p> <p>Hypokinetic-rigid</p> <p>Cautious</p> <p>Stiff</p> <p>Higher-level gait disorder</p>	<p>Gait patterns are not unequivocally attributed to a specific anatomic lesion (eg, wide-based gait might be caused by either frontal or cerebellar gait)</p> <p>Ancillary investigations (eg, MRI) are required</p> <p>Pathophysiology not taken into account</p> <p>Classification is driven by a mixture of etiologic, anatomic, and clinical features</p> <p>A patient might have one or more types of gait disturbance</p>

# Neurological disorders of gait, balance and posture: a sign-based approach

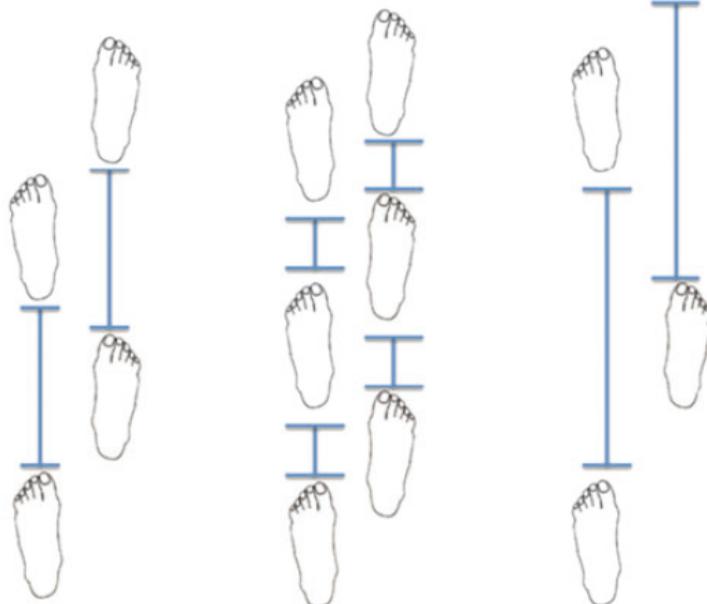
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*Jorik Nonnekes, Rianne J. M. Goselink, Evžen Růžička, Alfonso Fasano,  
John G. Nutt and Bastiaan R. Bloem*

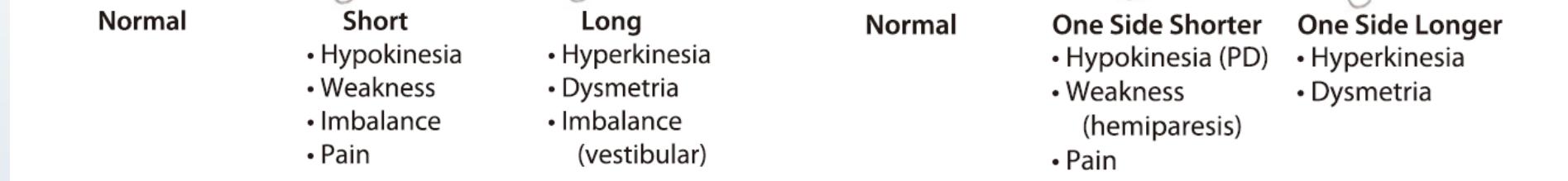
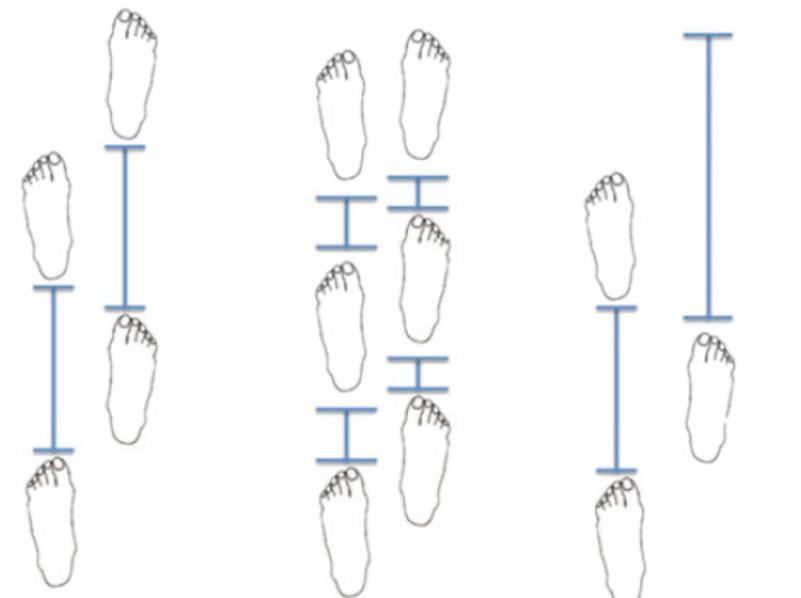
- Medical teaching programs typically take **classic clinical presentations** as the starting point and present students with a representative constellation of features that jointly characterize a particular axial motor syndrome.
- However, patients **rarely present** in this way to a physician in clinical practice.
- Particularly **in the early stages of a disease**, patients might display just one (or at best only a few) abnormal signs of gait, balance or posture.
- Importantly, these individual signs are never pathognomonic for any specific disorder but rather come with an associated differential diagnosis.

# Spatiotemporal parameters

Length/height



Symmetry



# Recent perspective: Sign-based approach

Table 1 | Abnormalities observed during sitting, rising from a chair, and quiet standing

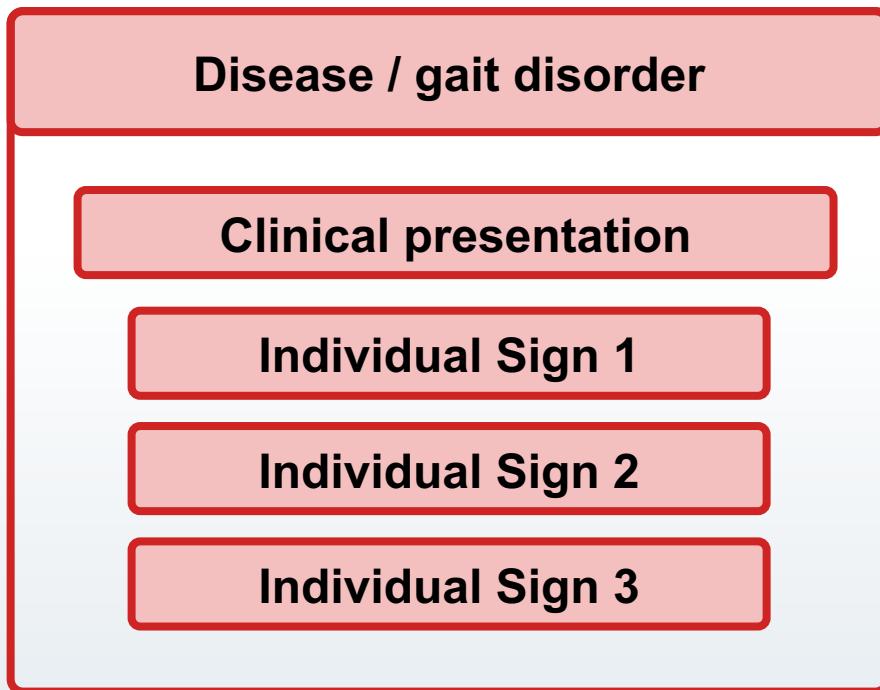
Abnormalities	Suggestions for the differential diagnosis*
<b>Sitting</b>	
Leaning sideways	<ul style="list-style-type: none"> <li>Vertebral column deformities</li> <li>Pisa syndrome: either drug-induced (for example, dopamine receptor antagonists) or associated with neurodegeneration (AD, PD, atypical parkinsonism)</li> <li>Pusher syndrome (unilateral thalamic stroke), trunk dystonias (including idiopathic Pisa syndrome)</li> </ul>
Drifting backwards	<ul style="list-style-type: none"> <li>PD, atypical parkinsonism (PSP)</li> <li>Higher-level gait disorders</li> <li>Trunk dystonia (opisthotonus), often drug-induced (dopamine receptor antagonists)</li> </ul>
Forwards dropping of the head (disproportionate antecolis)	<ul style="list-style-type: none"> <li>MSA, ALS, myasthenia gravis, polymyositis, focal posterior cervical myositis</li> <li>Drug-induced (dopamine receptor antagonists, amantadine)</li> </ul>
Backwards dropping of the head (retrocollis)	<ul style="list-style-type: none"> <li>PSP, cervical dystonia, young-onset PD</li> <li>Drug-induced (dopamine receptor antagonists)</li> </ul>
<b>Rising from a chair</b>	
Inappropriate motor strategies (for example, feet not brought under the body)	Higher-level gait disorders
Slow, requiring multiple attempts, or needing to push off with arms	<ul style="list-style-type: none"> <li>Nonspecific</li> <li>Proximal weakness, PD, higher-level gait disorders</li> </ul>
Reckless rising ('rocket sign')	Early PSP
Shaking of the legs upon standing (negative orthostatic myoclonus)	Idiopathic orthostatic myoclonus, history of postanoxic encephalopathy, frontal vascular lesions, atypical parkinsonism, AD, normal-pressure hydrocephalus
Legs wide apart while arising	<ul style="list-style-type: none"> <li>Sensitive but nonspecific</li> <li>Vestibular ataxia, sensory ataxia, cerebellar ataxia, atypical parkinsonism, chorea</li> </ul>
<b>Quiet standing (eyes open)</b>	
Normal to narrowed base of support	PD, spastic paraparesis
Widened base of support	<ul style="list-style-type: none"> <li>Sensitive but nonspecific</li> <li>Vestibular ataxia, sensory ataxia, cerebellar ataxia, chorea</li> <li>Atypical parkinsonism</li> </ul>
Progressive instability	Orthostatic tremor, negative myoclonus, functional gait disorders
Excessive spontaneous sway	Dyskinesias (for example, PD, Huntington disease), higher-level gait disorders, functional gait disorders
Leaning or drifting sideways	<ul style="list-style-type: none"> <li>Vertebral column deformities</li> <li>Pisa syndrome: either drug-induced (for example, dopamine receptor antagonists) or associated with neurodegeneration (AD, PD, atypical parkinsonism)</li> <li>Pusher syndrome (unilateral thalamic stroke), trunk dystonias (including idiopathic Pisa syndrome)</li> </ul>
Excessive trunk flexion that persists when lying down	Vertebral column deformities
Excessive trunk flexion that disappears when lying down	<ul style="list-style-type: none"> <li>Trunk or hip weakness (myasthenia gravis, motor neuron disease, myopathies)</li> <li>Camptocormia (PD, atypical parkinsonism)</li> </ul>

Table 2 | Abnormalities observed during the walking component of the clinical assessment

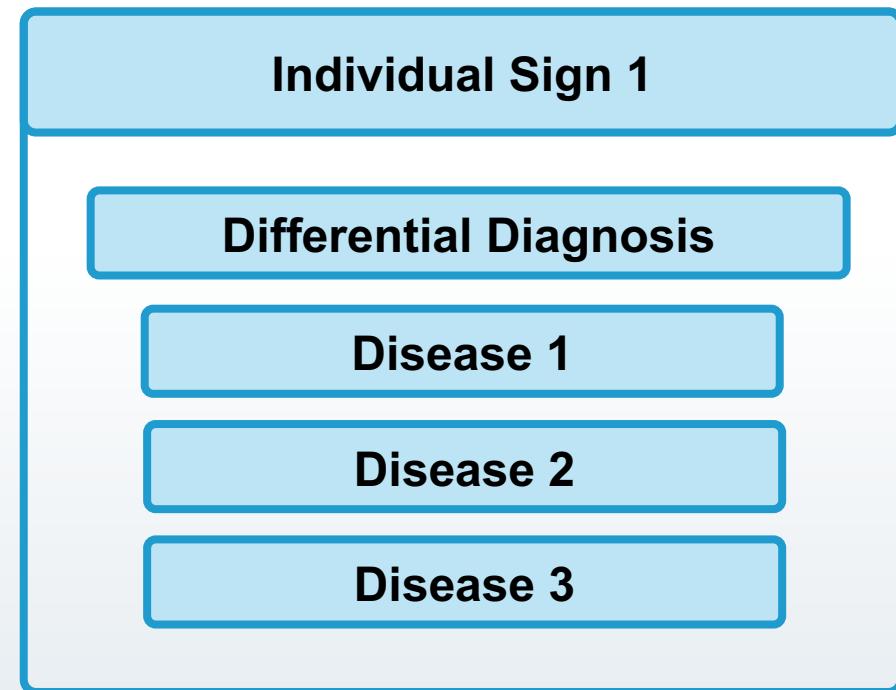
Abnormalities	Suggestions for the differential diagnosis*
<b>Gait initiation, maintenance and termination</b>	
Difficulty starting	<ul style="list-style-type: none"> <li>PD, atypical parkinsonism; primary progressive freezing of gait; other causes of 'lower-body' parkinsonism (for example, normal-pressure hydrocephalus, vascular parkinsonism)</li> </ul>
Sudden episodes of inability to step, particularly when turning or passing through doorways (freezing of gait)	<ul style="list-style-type: none"> <li>PD, atypical parkinsonism; primary progressive freezing of gait; other causes of 'lower-body' parkinsonism (for example, normal-pressure hydrocephalus, vascular parkinsonism)</li> </ul>
Inability to stop (festination)	<ul style="list-style-type: none"> <li>PD, atypical parkinsonism; other causes of 'lower-body' parkinsonism (for example, normal-pressure hydrocephalus, vascular parkinsonism)</li> </ul>
<b>Stance width</b>	
Narrowed base of support	PD, spastic paraparesis (for example, hereditary spastic paraparesis)
Widened base of support	<ul style="list-style-type: none"> <li>Nonspecific</li> <li>Atypical parkinsonism, cerebellar ataxia, sensory ataxia, vestibular ataxia, higher-level gait disorders</li> <li>Extreme in some functional gait disorders</li> </ul>
Scissoring of the legs	<ul style="list-style-type: none"> <li>Spastic paraparesis (for example, juvenile cerebral palsy), dystonia, higher-level gait disorders, Huntington disease (due to chorea), compensation for freezing of gait (for example, in PD), functional gait disorders</li> </ul>
Unable to walk in a straight line, sideways deviation (veering) of gait	Unilateral vestibular ataxia, unilateral cerebellar ataxia (consistently veering in a direction ipsilateral to the lesion), functional gait disorders (often veering from side to side)
<b>Step length, height and cadence</b>	
Reduced step height	<ul style="list-style-type: none"> <li>PD, parkinsonism; foot drop (due to neuropathy of common fibular nerve or sciatic nerve, LS radiculopathy, Charcot-Marie-Tooth disease, muscular dystrophy, stroke or multiple sclerosis causing distal weakness)</li> </ul>
Small steps	<ul style="list-style-type: none"> <li>Sensitive but nonspecific</li> <li>Caused by pain (for example, orthopaedic disorders)</li> <li>Caused by underlying pathology: common in PD, atypical parkinsonism, normal-pressure hydrocephalus; severe sensory impairment of the legs</li> <li>Compensation for perceived instability</li> </ul>
Irregular step size (cadence)	Cerebellar ataxia, vestibular ataxia, higher-level gait disorders, chorea, essential tremor
Reduced stance phase on the affected side (limping)	Pain (allogic gait) resulting from trauma or arthritis; functional gait disorders
<b>Arm swing</b>	
Unilaterally reduced	Hemiparesis, dystonia, PD, orthopaedic or rheumatological disorders affecting the elbow or shoulder joint unilaterally
Bilaterally reduced	PD, parkinsonism, dystonia, orthopaedic or rheumatological disorders affecting the elbow or shoulder joint bilaterally
Excessive	Chorea, levodopa-induced dyskinesias, normal-pressure hydrocephalus (as compensation for poor body propulsion), hypotonia, functional gait disorders
Tremor appearing in hand during walking	PD, parkinsonism
Posturing with the arm	PD, dystonia, secondary to shoulder and/or neck injury, alien limb phenomenon, functional gait disorders
<b>Movement fluidity</b>	
Dropped foot, lifting the leg higher than normal (steppage gait)	<ul style="list-style-type: none"> <li>Neuropathy of common fibular nerve or sciatic nerve, LS radiculopathy, Charcot-Marie-Tooth disease, muscular dystrophy or myopathy; stroke or multiple sclerosis causing distal weakness; foot dystonia causing a functional lengthening of the leg</li> </ul>
Knees giving way (buckling of the knees)	Functional gait disorders, quadriceps weakness (for example, limb-girdle myopathy, IBM), cataplexy, negative myoclonus, dystonia
Locking of the knees	<ul style="list-style-type: none"> <li>Cerebellar ataxia, severe arthrosis or arthritis of the knees; compensation for quadriceps weakness (for example, limb-girdle myopathy, IBM); compensation for severe sensory impairments of the legs; increased external knee extension moment because of pes equinus (due to upper motor neuron syndrome)</li> </ul>
Pelvis drop at side of the swing leg, resulting in alternating lateral trunk movements (waddling gait, bilateral Trendelenburg gait)	Bilateral proximal muscle weakness in the leg and hip girdle; common in muscular dystrophy (for example, LGMD, FSHD, Duchenne muscular dystrophy) and metabolic myopathy (for example, thyroid myopathy); bilateral LS radiculopathy resulting in weakness of gluteus medius, secondary to joint instability (as in Ehlers-Danlos syndrome)
Stiff gait	Many disorders, including myotonia, dystonia, stiff man (or stiff leg) syndrome
Bizarre gait pattern	Chorea (including levodopa-induced dyskinesias), dystonia, higher-level gait disorders, functional gait disorders
<b>Abnormalities</b>	
<b>Movement fluidity (cont.)</b>	
Twisting of the foot (varus deviation of the hindfoot)	<ul style="list-style-type: none"> <li>Fixed or dynamic varus due to muscular imbalance around the ankle and tarsal joints (for example, due to upper motor neuron syndrome), young-onset PD (exercise-induced dystonia), cerebrovascular (or other) basal ganglia lesion resulting in dystonia, corticobasal degeneration resulting in dystonia, primary dystonia, functional gait disorders</li> </ul>
<b>Gait speed</b>	
Slow	<ul style="list-style-type: none"> <li>Nonspecific</li> <li>Perceived imbalance, PD, higher-level gait disorders, functional gait disorders, pain caused by orthopaedic disorders, advanced stages of PSP</li> </ul>
Fast, safe	Vestibular syndromes, orthostatic tremor
Fast, unsafe	AD, frontal disinhibition, early stages of PSP

# Approach to gait disorders

## Classic approach



## Sign-based approach



# Approach to neurologic diseases

## : Example - PD

### Classic approach

**Parkinson's Disease**

**Clinical presentation**

**Bradykinesia**

**Rest tremor**

**Rigidity**

### Sign-based approach

**Bradykinesia**

**Differential Diagnosis**

**Parkinson's Disease**

**MSA-P**

**PSP**

# **Walking protocol for instrumental gait analysis**

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# Walking protocols comparison

**Table 2**

Summary of the variability (within-person SD) of gait characteristics, and reliability and sample size estimates for gait variability outcomes for test 1 (T1) and test 2 (T2).

Group	Condition	Variable	SD T1	SD T2	Difference (T2 – T1)	LoA	LoA%	ICC	Sample size estimates		
									10%	20%	30%
Control	Continuous	Velocity (cm/s)	4.87	4.76	-.11	1.98	40.7	.553	94	18	8
		Step Length (cm)	1.89	1.86	-.03	.98	53.4	.652	96	30	14
		Step Width (cm)	2.26	2.11	-.15*	.74	34.1	.752	70	13	6
		Step Time (ms)	17.95	15.45	-2.50*	10.9	64.9	.598	141	44	20
		Swing Time (ms)	17.15	14.45	-2.70*	12.0	76.0	.590	171	61	27
	Intermittent	Stance Time (ms)	20.50	17.30	-3.20	16.8	89.0	.558	241	83	37
		Velocity (cm/s)	4.75	4.96	.21	3.42	70.5	.183	207	52	23
		Step Length (cm)	1.74	1.81	.07	1.45	81.8	.451	279	70	31
		Step Width (cm)	1.92	2.06	.14	1.74	87.2	.041	317	80	36
		Step Time (ms)	16.95	15.65	-1.30	9.1	55.5	.820	129	33	15
PD	Continuous	Swing Time (ms)	15.20	14.80	-.40	8.4	56.1	.839	132	33	15
		Stance Time (ms)	20.00	18.20	-1.80	11.5	60.5	.834	153	39	17
		Velocity (cm/s)	4.69	4.94	.25	2.58	53.6	.388	120	30	14
		Step Length (cm)	2.01	2.04	.03	.87	43.0	.749	78	20	9
		Step Width (cm)	1.83	1.84	.01	.88	48.2	.648	97	25	11
		Step Time (ms)	18.55	17.65	-1.10	9.2	50.6	.819	107	27	12
		Swing Time (ms)	16.90	15.90	-1.0	8.1	49.3	.773	102	26	12
	Intermittent	Stance Time (ms)	21.35	21.45	.10	13.0	60.6	.860	154	39	18
		Velocity (cm/s)	4.73	4.54	-.19	2.79	60.1	.460	151	38	17
		Step Length (cm)	1.97	1.96	-.01	1.21	61.7	.695	159	40	18
		Step Width (cm)	1.72	1.68	-.04	1.27	47.8	.512	234	59	26
		Step Time (ms)	16.85	16.96	.11	11.3	67.3	.637	189	48	21
		Swing Time (ms)	16.85	16.95	.10	11.1	66.1	.678	183	46	21
		Stance Time (ms)	18.42	18.38	-.04	13.5	73.5	.784	225	57	25

T1: Test 1; T2: Test 2; LoA: limits of agreement; LoA%: limits of agreement as a percentage of the mean of Test 1 and Test 2; Sample size estimates refer to the number of participants required in each group to detect a 10%, 20% or 30% difference between the two groups using an independent *t*-test with 80% power and  $\alpha=5\%$ , assuming at least 50 steps are used to calculate variability.

\* A significant bias between test 1 and test 2 at  $p < .05$ .

We recommend using a continuous walking protocol and to collect no fewer than 30 steps.

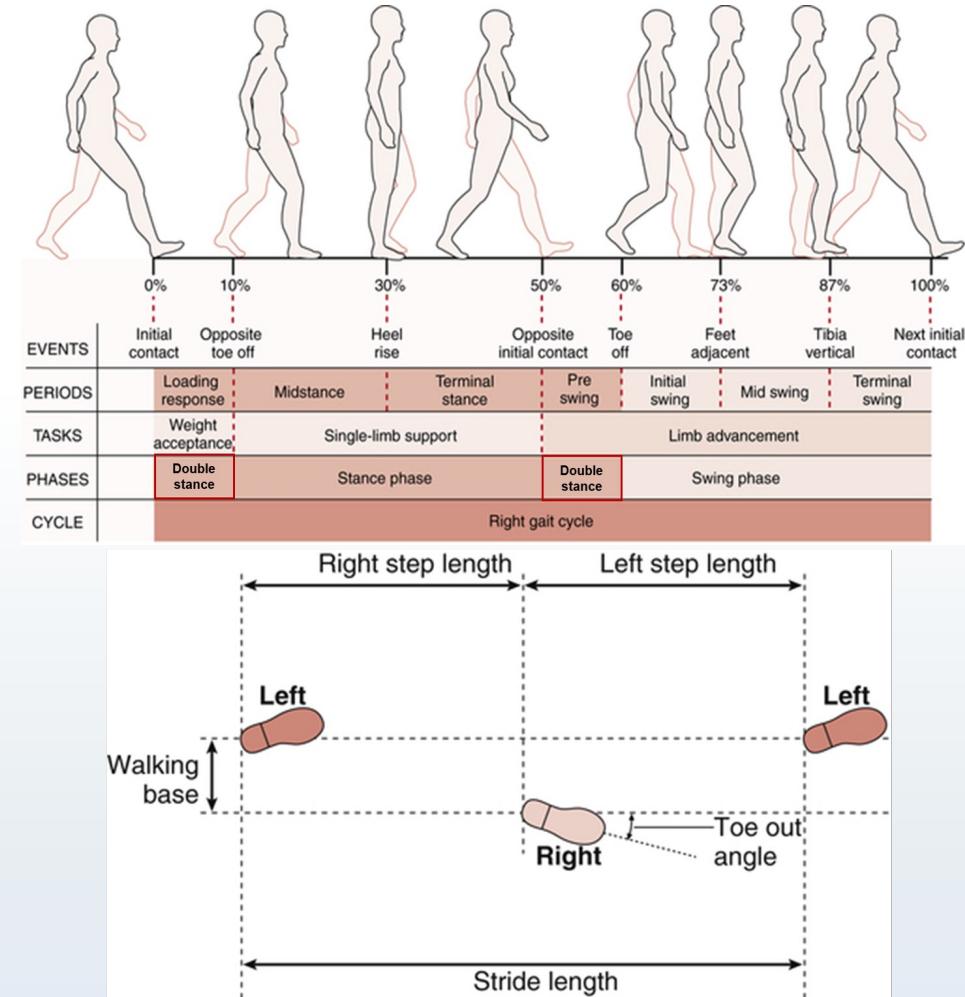
# Demonstration: Normal Walking

## Parameters

Distance (cm)	1779.7
Ambulation Time (sec)	11.76
Velocity (cm/sec)	151.3
Mean Normalized Velocity	.00

Cadence (Steps/Min)	122.4
Step Time Differential (sec)	.02
Step Length Differential (cm)	2.22
Cycle Time Differential (sec)	.00

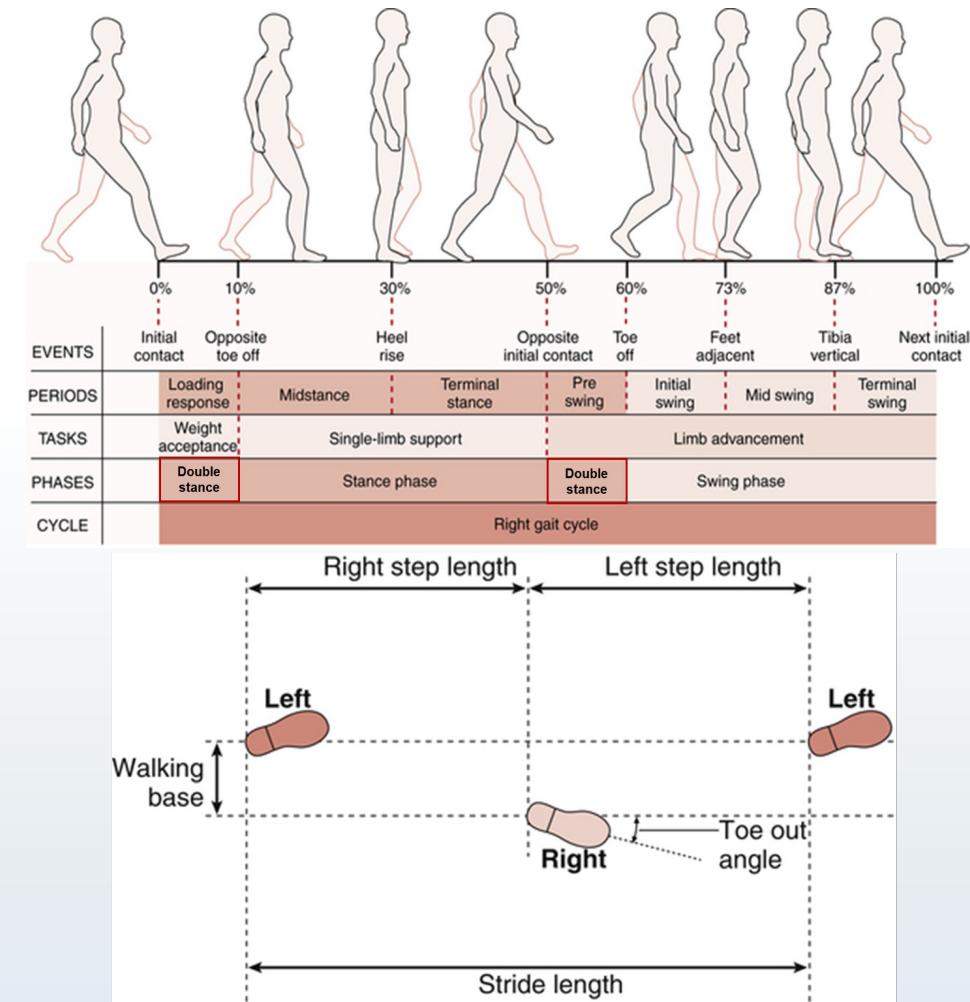
Walk # / Footfall #	L/R	Mean(%CV)	Sample Normal Values
Step Time (sec)	L	.499(2.6)	
	R	.478(2.3)	0.53 0.59
Cycle Time (sec)	L	.977(1.7)	
	R	.976(1.7)	1.06 1.18
Swing Time (sec) / %GC	L	.403(3.0) /41.2	
	R	.382(2.4) /39.1	36 44
Stance (sec) / %GC	L	.574(3.1) /58.8	
	R	.594(3.5) /60.9	56 64
Single Support (sec) / %GC	L	.382(2.4) /39.1	
	R	.403(3.0) /41.3	38 42
Double Support (sec) / %GC	L	.190(8.4) /19.4	
	R	.190(6.8) /19.5	16 24
Step Length (cm)	L	75.079(3.0)	
	R	72.862(2.6)	58 85
Stride Length (cm)	L	148.664(2.6)	
	R	147.799(2.9)	116 170
Base of Support (cm)	L	15.31(6.5)	
	R	15.69(3.9)	
Toe In / Out (deg)	L	14(0)	
	R	11(0)	



**Cadence:** Number of steps in a given time (e.g. steps per min)

# Reference Values for Gait Parameters

Variables	References of Normal adults
Walking velocity(cm/sec)	60-80 : decreased, tolerable <60 : decreased, intolerable
Cadence(steps/min)	90-120
Stride length differential(cm)	<2.5
Step Time	0.53-0.59
Cycle time	1.06-1.18
Swing time (% of GC)	36-44%
Stance time (% of GC)	56-64%
Single Support time(% of GC)	38-42%
Double Support time (% of GC)	16-24%
Step length (cm)	58-85, >8: increased
Stride length (cm)	116-170, >7: increased
Base support (cm)	5-10
Foot angle, toe in/out(deg)	3-7; normal, <3 : decreased

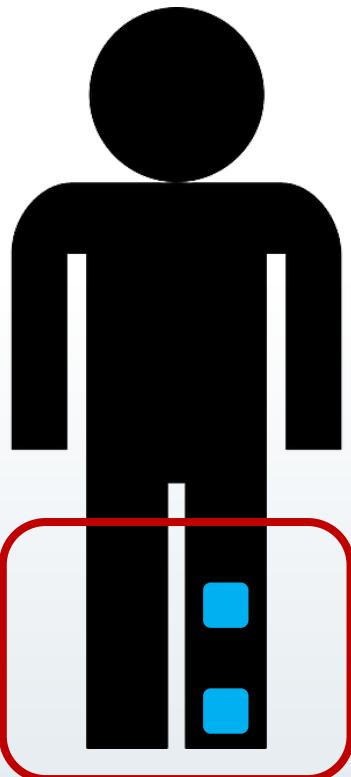


**Cadence:** Number of steps in a given time (e.g. steps per min)

# **Specific gait disorder review & application of gait analysis**

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# Antalgic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓	↓	↑↑	=	↑	Limping

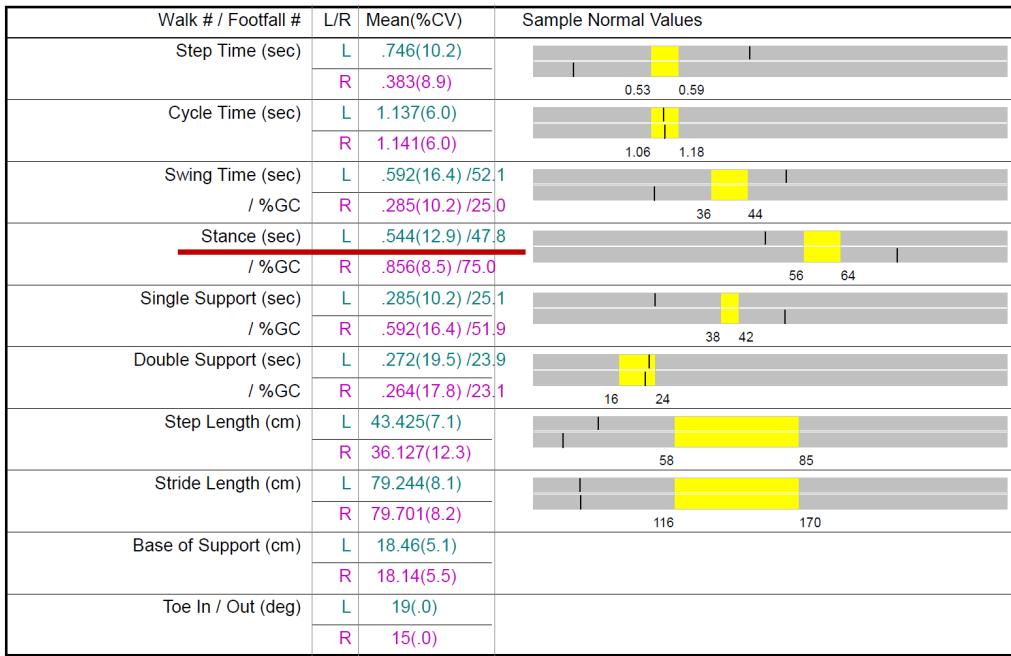
- Causes: orthopedic diseases
  - knee osteoarthritis, ankle sprain, foot fracture
- Affected limb: Decreased stance phase
- Unaffected limb: Decreased swing phase / step length

# Demonstration: Antalgic gait Lt

## Parameters

Distance (cm)	1236.7
Ambulation Time (sec)	17.69
Velocity (cm/sec)	69.9
Mean Normalized Velocity	.00

Cadence (Steps/Min)	105.1
Step Time Differential (sec)	.36
Step Length Differential (cm)	7.30
Cycle Time Differential (sec)	.00

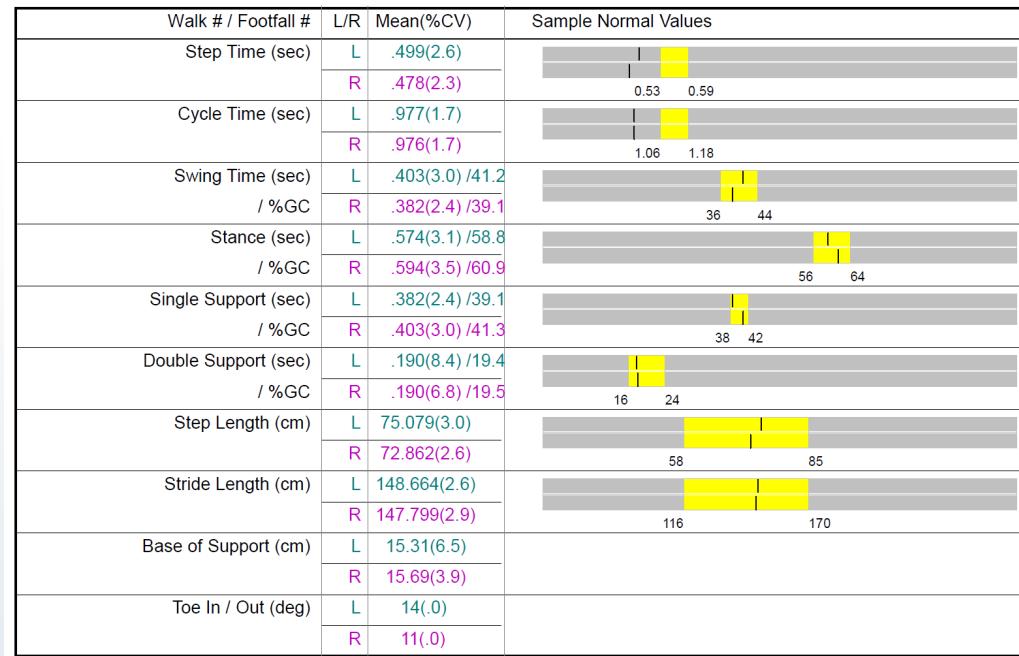


Demonstration

## Parameters

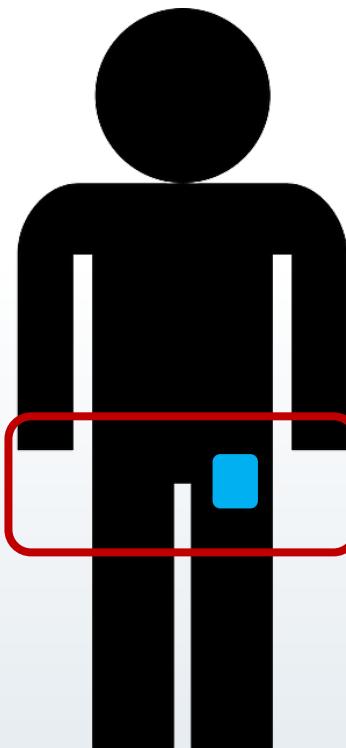
Distance (cm)	1779.7
Ambulation Time (sec)	11.76
Velocity (cm/sec)	151.3
Mean Normalized Velocity	.00

Cadence (Steps/Min)	122.4
Step Time Differential (sec)	.02
Step Length Differential (cm)	2.22
Cycle Time Differential (sec)	.00



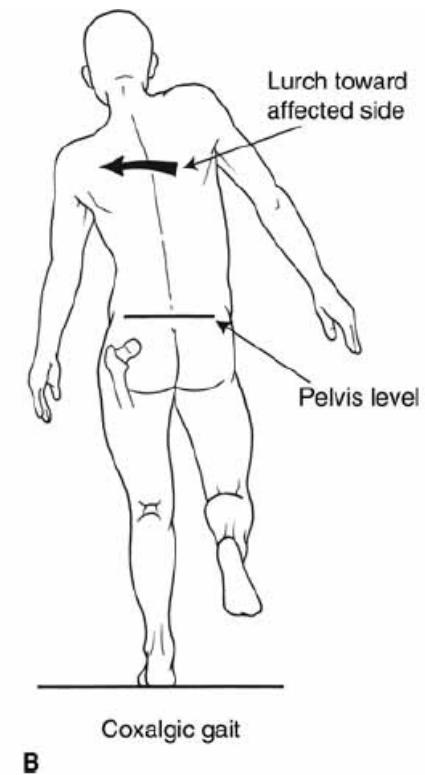
Normal

# Coxalgic gait

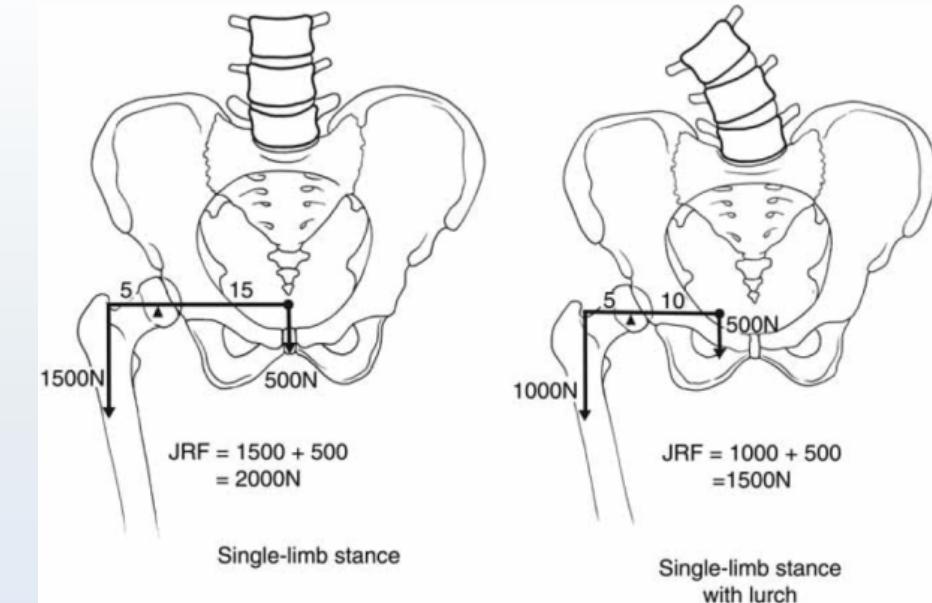


Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓	↓	↑↑	=	↑	Limping Truncal lurch

- Causes: hip osteoarthritis
- Lurch toward affected side
- Affected limb: Decreased stance phase
- No contralateral hemipelvis drop down



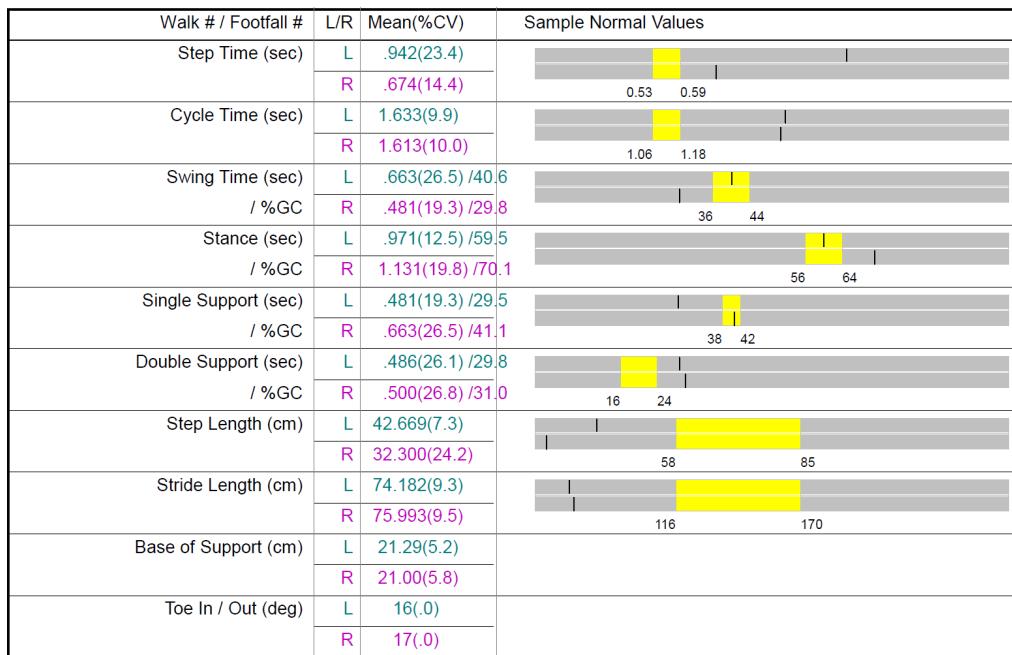
B



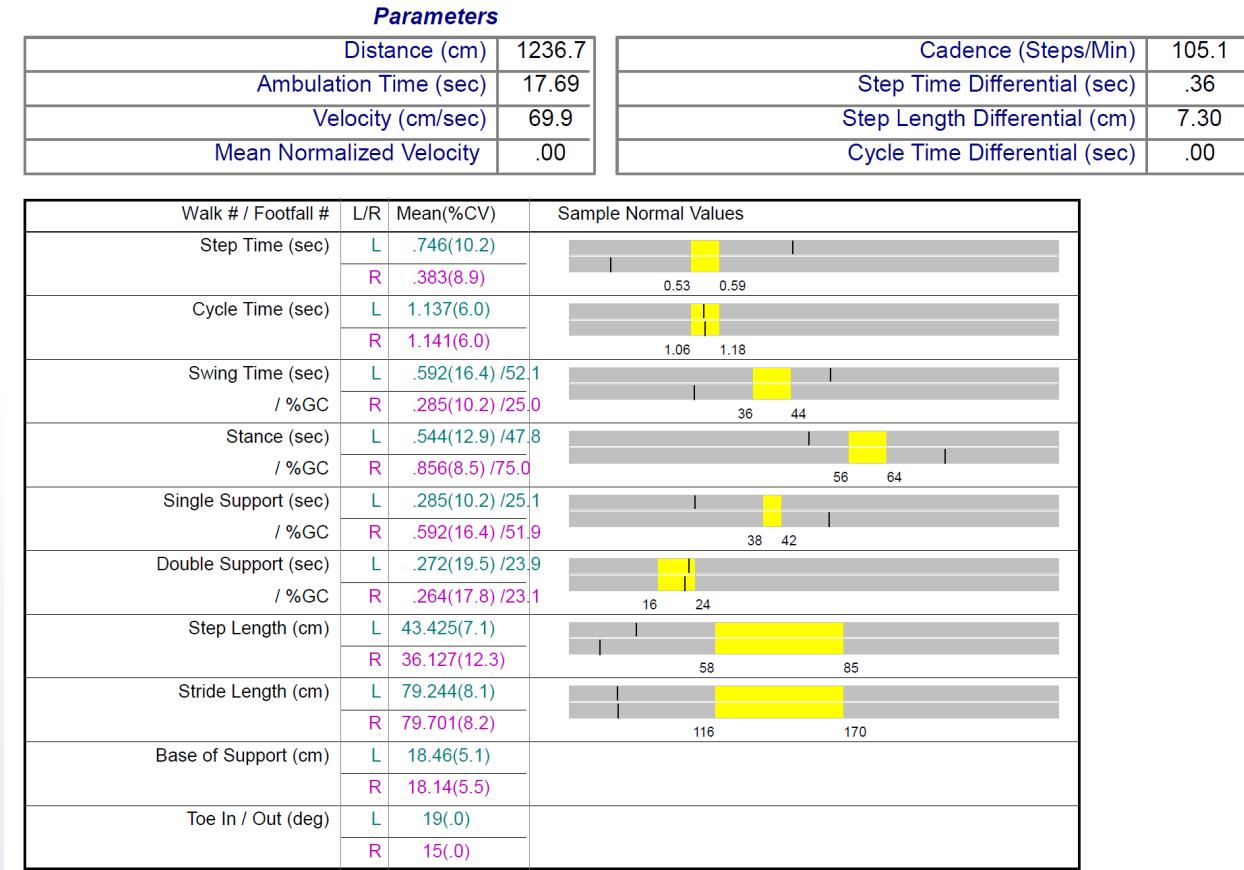
# Demonstration: Coxalgic gait Lt

Parameters	
Distance (cm)	1231.8
Ambulation Time (sec)	26.53
Velocity (cm/sec)	46.4
Mean Normalized Velocity	.00

Parameters	
Cadence (Steps/Min)	74.6
Step Time Differential (sec)	.27
Step Length Differential (cm)	10.37
Cycle Time Differential (sec)	.02

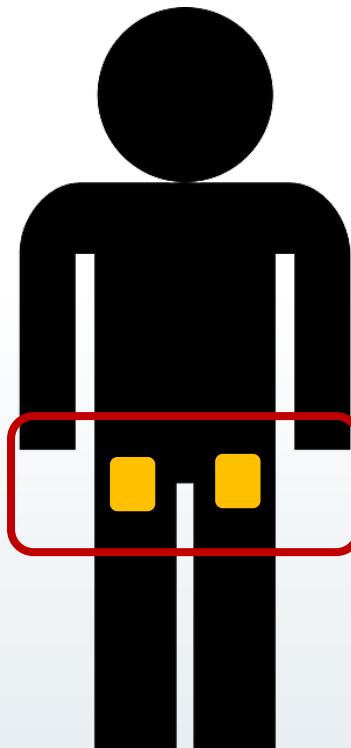


Coxalgic gait Lt



Antalgic gait Lt

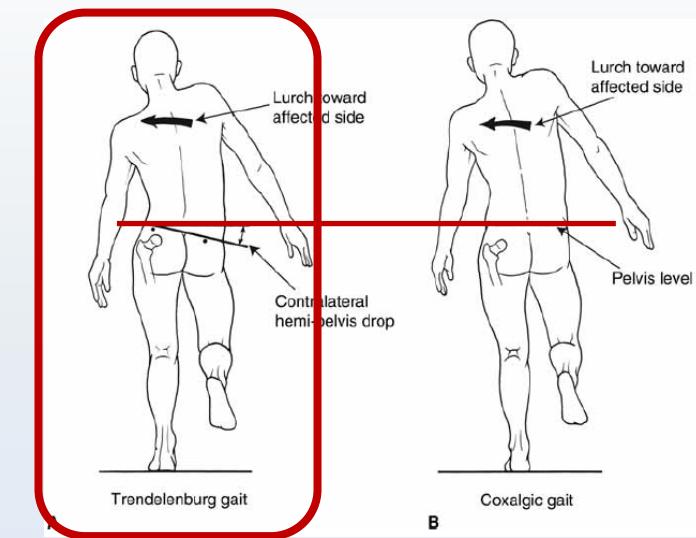
# Waddling gait (Trendelenburg gait)



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓/=	↓/=	↓/=	=	=	=/↑	Usually bilateral Trendelenburg sign



- Causes: pelvic girdle, proximal muscle weakness, myopathy
- **Trendelenburg sign:** lurch toward affected side / **contralateral hip drop due to gluteal muscle weakness**
- Compensation: Lumbar hyperlordosis + flexed posture

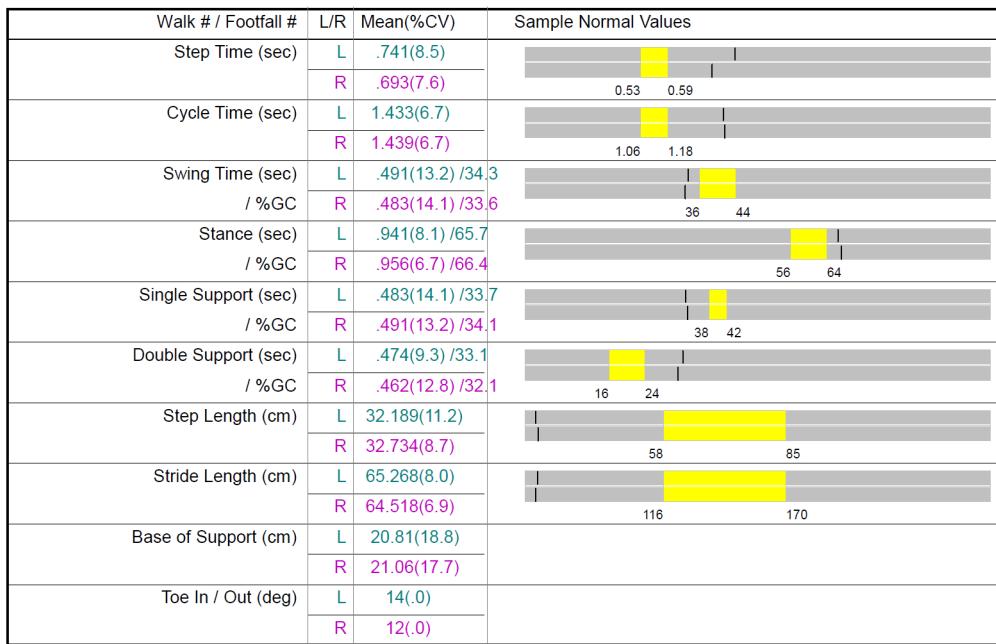


# Demonstration: Waddling gait

## Parameters

Distance (cm)	909.5
Ambulation Time (sec)	20.03
Velocity (cm/sec)	45.4
Mean Normalized Velocity	.00

Cadence (Steps/Min)	83.9
Step Time Differential (sec)	.05
Step Length Differential (cm)	.55
Cycle Time Differential (sec)	.01



## Bilateral Parameters

	Left	Right
Step Time (sec)	.81/14.5	.78/11.8
Cycle Time (sec)	1.59/10.4	1.59/11.3
Step Length (cm)	28.99/15.8	29.84/15.0
Stride Length (cm)	59.67/12.4	59.22/12.0
H-H Base Support (cm)	14.42	14.46
Single Support (%GC)	25.5	26.9
Double Support (%GC)	47.9	48.0
Swing (%GC)	26.9	25.4
Stance (%GC)	73.0	74.6
Step/Extremity Ratio	.36	.38
Toe In / Out (deg)	4	10

Functional Ambulation Profile: 55

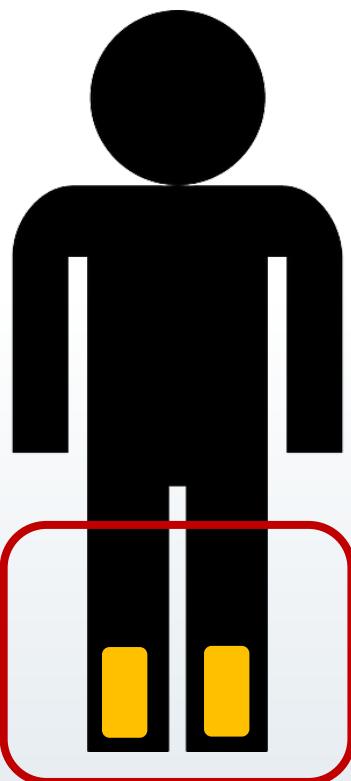
## Parameters

Distance (cm)	3852.9
Ambulation Time (sec)	104.05
Velocity (cm/sec)	37.0
Mean Normalized Velocity	.46
Number of Steps	131
Cadence (Steps/Min)	75.5
Step Time Differential (sec)	.03
Step Length Differential (cm)	.86
Cycle Time Differential (sec)	.00
FAP Deduction From	100
Step Functions Left	-22
Step Functions Right	-22
Diff Step Extr. Ratio	
HH Dyn. Base of Supp	-1
Ambulatory Aids	
Assistive Devices	
FAP Score	55

Demonstration

78/F Myopathy

# Steppage gait (distal weakness)



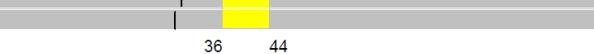
Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓/≡	↓/≡	↓↑	=/↑	=	=/↑	Foot-drop Drag-to gait

- Causes: distal muscle weakness, neuropathy
- **Steppage gait**: lift the leg higher, ankle dorsiflexion weakness
- **Drag-to gait**: dragging d/t weak push-off, calf muscle weakness

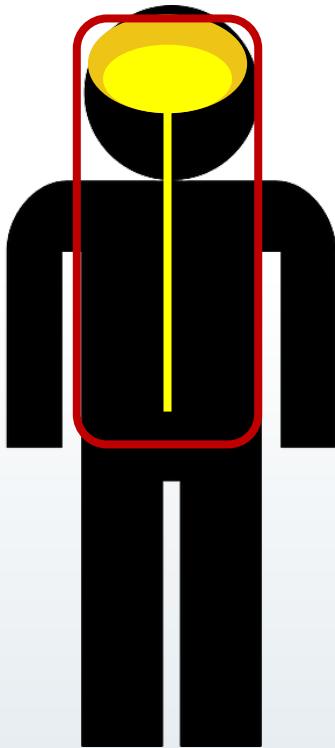
# Demonstration: Steppage gait

## Parameters

Distance (cm)	1208.8	Cadence (Steps/Min)	42.5
Ambulation Time (sec)	36.72	Step Time Differential (sec)	.01
Velocity (cm/sec)	32.9	Step Length Differential (cm)	3.06
Mean Normalized Velocity	.00	Cycle Time Differential (sec)	.02

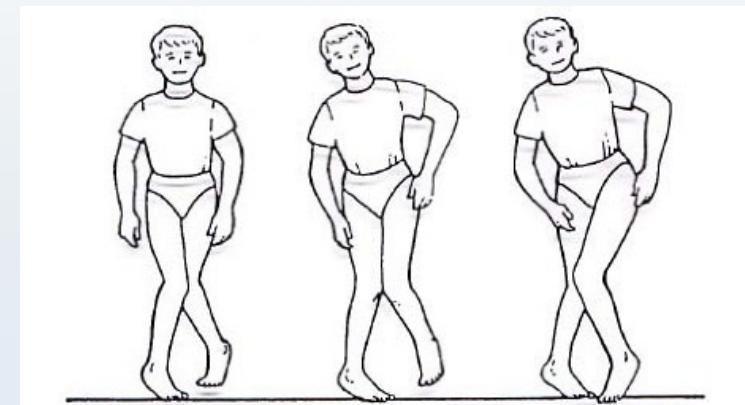
Walk # / Footfall #	L/R	Mean(%CV)	Sample Normal Values
Step Time (sec)	L	1.407(7.1)	 0.53 0.59
	R	1.417(7.8)	
Cycle Time (sec)	L	2.819(7.2)	 1.06 1.18
	R	2.840(7.1)	
Swing Time (sec) / %GC	L	.846(10.2) /30.0	 36 44
	R	.821(8.3) /28.9	
Stance (sec) / %GC	L	1.973(10.8) /70.0	 56 64
	R	2.019(8.6) /71.1	
Single Support (sec) / %GC	L	.821(8.3) /29.1	 38 42
	R	.846(10.2) /29.8	
Double Support (sec) / %GC	L	1.134(14.6) /40.2	 16 24
	R	1.125(18.5) /39.6	
Step Length (cm)	L	48.136(8.5)	 58 85
	R	45.081(6.0)	
Stride Length (cm)	L	93.269(6.6)	 116 170
	R	92.678(6.8)	
Base of Support (cm)	L	21.90(6.0)	
	R	22.01(5.4)	
Toe In / Out (deg)	L	12(0)	
	R	8(0)	

# Spastic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓	↓	=/↑↑	=/↑/↓	↑	Weakness Circumduction Scissoring

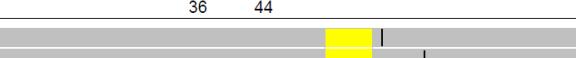
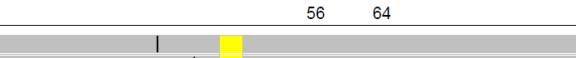
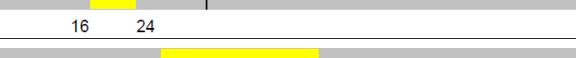
- Causes: Hemiparesis or paraparesis
- **Stiff gait:** knee extension, plantar flexion in swing phase
- **Spastic hemiparetic gait:** circumduction, lurch to intact side
- **Spastic paraparetic gait:** myelopathy, cerebral palsy, scissor gait



# Demonstration: Spastic gait Lt

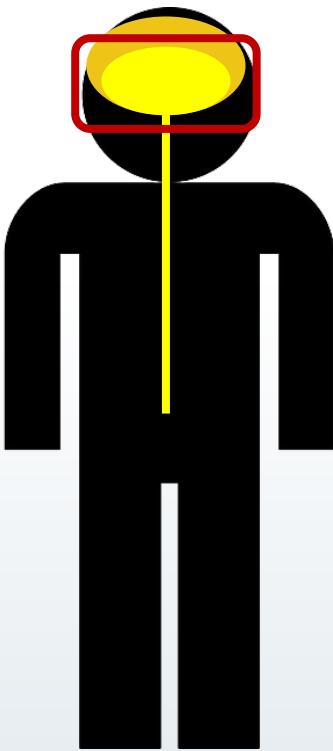
## Parameters

Distance (cm)	1272.3	Cadence (Steps/Min)	57.9
Ambulation Time (sec)	38.33	Step Time Differential (sec)	.06
Velocity (cm/sec)	33.2	Step Length Differential (cm)	6.41
Mean Normalized Velocity	.00	Cycle Time Differential (sec)	.03

Walk # / Footfall #	L/R	Mean(%CV)	Sample Normal Values
Step Time (sec)	L	1.063(5.1)	 0.53 0.59
	R	1.008(11.2)	
Cycle Time (sec)	L	2.048(6.6)	 1.06 1.18
	R	2.076(6.6)	
Swing Time (sec) / %GC	L	.719(6.7) /35.1	 36 44
	R	.585(13.2) /28.2	
Stance (sec) / %GC	L	1.330(10.8) /64.9	 56 64
	R	1.491(8.1) /71.8	
Single Support (sec) / %GC	L	.585(13.2) /28.6	 38 42
	R	.719(6.7) /34.6	
Double Support (sec) / %GC	L	.766(14.8) /37.4	 16 24
	R	.757(16.6) /36.5	
Step Length (cm)	L	31.269(20.3)	 58 85
	R	37.675(13.6)	
Stride Length (cm)	L	69.221(6.5)	 116 170
	R	67.866(6.0)	
Base of Support (cm)	L	20.38(8.8)	
	R	20.25(9.7)	
Toe In / Out (deg)	L	17(0)	
	R	10(0)	

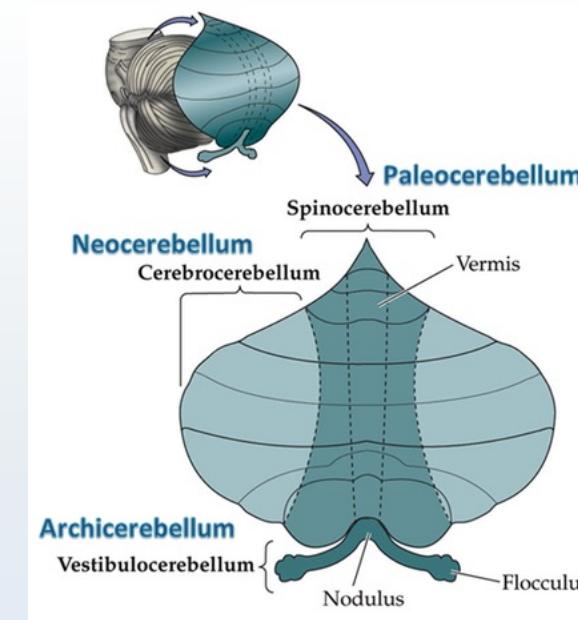
# Ataxic gait

## - Cerebellar ataxic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓	=/↑	=	↑↑	↑	Ataxia Staggering

- Causes: cerebellar ataxia
- Neocerebellar lesion
  - Limb ataxia
  - Relatively uncommon falls
- Paleocerebellum
  - Severe postural instability
  - Frequent falls



# Demonstration: Ataxic gait

## Increased variability ! (CV)

### Parameters

Distance (cm)	914.4
Ambulation Time (sec)	20.26
Velocity (cm/sec)	45.1
Mean Normalized Velocity	.00

Cadence (Steps/Min)	94.8
Step Time Differential (sec)	.05
Step Length Differential (cm)	4.08
Cycle Time Differential (sec)	.04

### Walk # / Footfall #

	L/R	Mean(%CV)	Sample Normal Values
Step Time (sec)	L	.660(26.4)	0.53 0.59
	R	.610(25.4)	
Cycle Time (sec)	L	1.283(17.2)	1.06 1.18
	R	1.244(17.8)	
Swing Time (sec)	L	.417(29.3) /32.5	36 44
/ %GC	R	.392(23.7) /31.5	
Stance (sec)	L	.866(17.1) /67.5	56 64
/ %GC	R	.852(20.3) /68.5	
Single Support (sec)	L	.392(23.7) /30.6	38 42
/ %GC	R	.417(29.3) /33.5	
Double Support (sec)	L	.443(20.1) /34.5	16 24
/ %GC	R	.429(18.6) /34.5	
Step Length (cm)	L	30.739(28.5)	58 85
	R	26.663(15.6)	
Stride Length (cm)	L	58.785(12.7)	116 170
	R	58.611(13.8)	
Base of Support (cm)	L	21.47(24.2)	
	R	20.18(25.8)	
Toe In / Out (deg)	L	23(0)	
	R	16(0)	

Demonstration

### Bilateral Parameters

	Left	Right
Step Time (sec)	.60/14.6	.57/12.0
Cycle Time (sec)	1.16/10.6	1.17/10.8
Step Length (cm)	37.09/20.7	37.81/16.1
Stride Length (cm)	75.74/14.9	74.87/16.9
H-H Base Support (cm)	14.36	14.75
Single Support (%GC)	34.9	37.9
Double Support (%GC)	27.2	26.3
Swing (%GC)	38.4	34.4
Stance (%GC)	61.6	65.6
Step/Extremity Ratio	.43	.43
Toe In / Out (deg)	5	1

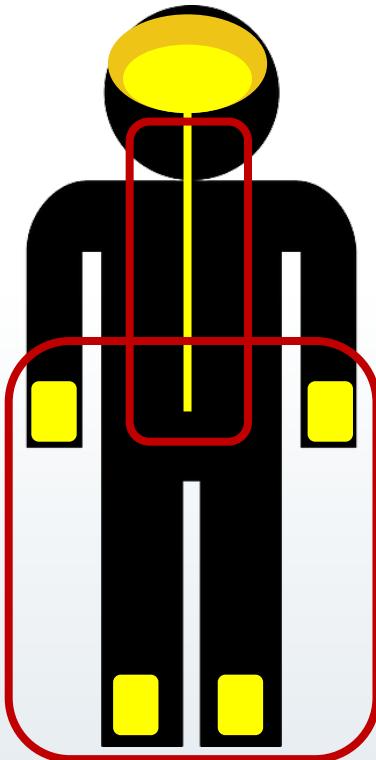
M/76 Cerebellar ataxia

Walk # / Footfall #	L/R	Mean(%CV)
Step Time (sec)	L	.499(2.6)
	R	.478(2.3)
Cycle Time (sec)	L	.977(1.7)
	R	.976(1.7)
Swing Time (sec)	L	.403(3.0) /41.2
	R	.382(2.4) /39.1
Stance (sec)	L	.574(3.1) /58.8
	R	.594(3.5) /60.9
Single Support (sec)	L	.382(2.4) /39.1
	R	.403(3.0) /41.3
Double Support (sec)	L	.190(8.4) /19.4
	R	.190(6.8) /19.5
Step Length (cm)	L	75.079(3.0)
	R	72.862(2.6)
Stride Length (cm)	L	148.664(2.6)
	R	147.799(2.9)
Base of Support (cm)	L	15.31(6.5)
	R	15.69(3.9)
Toe In / Out (deg)	L	14(0)
	R	11(0)

Normal

# Ataxic gait

## - Sensory ataxic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓	=/↑	=	↑↑	↑	Dysmetria Romberg sign Staggering

- Causes: proprioceptive dysfunction, sensory polyneuropathy, dorsal column lesions
- Loss of visual function causes marked worsening of ataxia
  - Romberg test, walking with closed eye
- Stomping gait



# M/66 Sensory ataxic gait

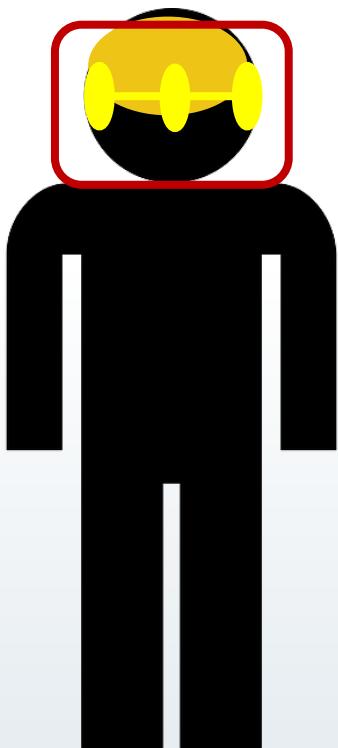
**Functional Ambulation Profile: 65**

<i>Bilateral Parameters</i>	<i>Left</i>	<i>Right</i>	<i>Parameters</i>	
Step Time (sec)	.63/6.7	.68/8.6	Distance (cm)	3778.9
Cycle Time (sec)	1.29/6.7	1.29/5.6	Ambulation Time (sec)	69.97
Step Length (cm)	37.24/8.5	33.50/8.9	Velocity (cm/sec)	54.0
Stride Length (cm)	71.43/6.7	71.46/6.5	Mean Normalized Velocity	.62
H-H Base Support (cm)	14.00	13.93	Number of Steps	107
Single Support (%GC)	28.8	31.8	Cadence (Steps/Min)	91.8
Double Support (%GC)	38.9	39.5	Step Time Differential (sec)	.05
Swing (%GC)	31.8	28.8	Step Length Differential (cm)	3.75
Stance (%GC)	68.2	71.2	Cycle Time Differential (sec)	.00
Step/Extremity Ratio	.43	.38		
Toe In / Out (deg)	13	8		

FAP Deduction From	100
Step Functions Left	-13
Step Functions Right	-20
Diff Step Extr. Ratio	-1
HH Dyn. Base of Supp	-1
Ambulatory Aids	
Assistive Devices	
FAP Score	65

# Ataxic gait

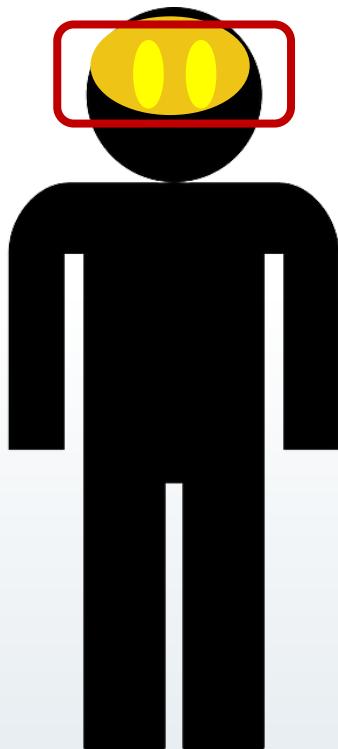
## - Vestibular ataxic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↑	↑	=/↑	=	=/↑	↑	Nystagmus, N/V Staggering

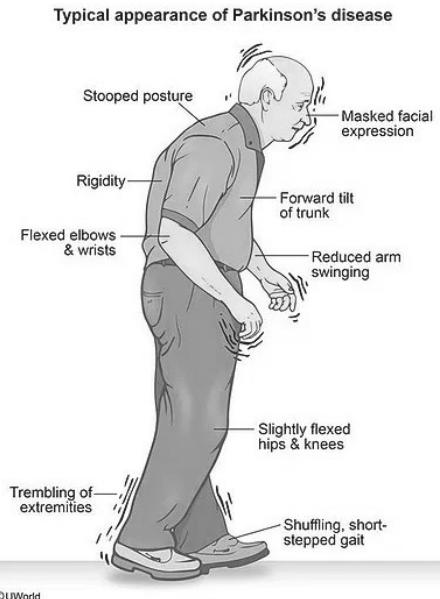
- Causes: unilateral / bilateral vestibulopathy, Meniere disease
- Vestibular symptoms and signs
  - Nystagmus, nausea/vomiting
- Acute dysfunction: **deviation to lesion side**
- **Veering gait:** consistent deviation from a straight line d/t unilateral chronic vestibular dysfunction
- **Loss of visual function causes marked worsening**

# Bradykinetic/hypokinetic gait - Parkinsonian gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↑	↓	↑	↓/≡	↑	Parkinsonism Flexed posture Shuffling

- Causes: Parkinson disease, Parkinson+
- Other characteristics may overlap
  - Freezing of gait, dyskinetic gait, higher-level gait disorder

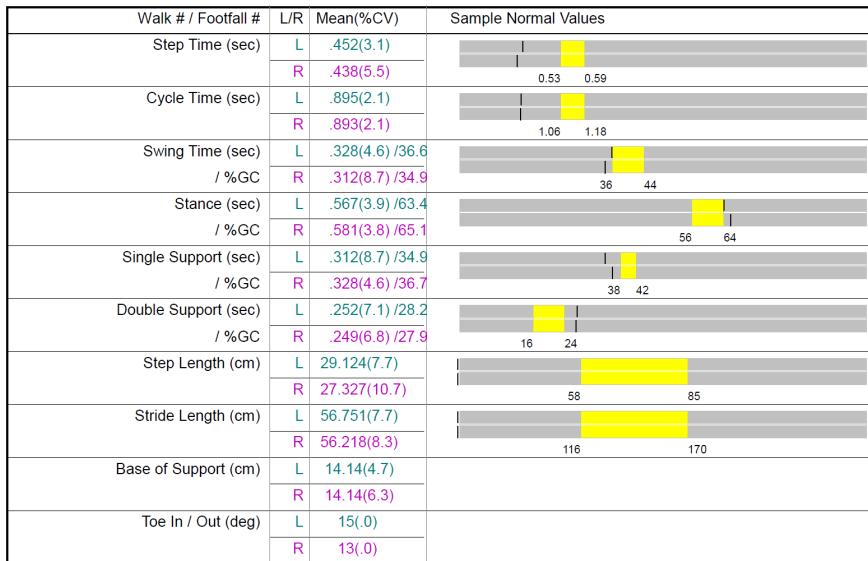


# Demonstration: Parkinsonian gait

## Parameters

Distance (cm)	959.7
Ambulation Time (sec)	15.13
Velocity (cm/sec)	63.4
Mean Normalized Velocity	.00

Cadence (Steps/Min)	134.8
Step Time Differential (sec)	.01
Step Length Differential (cm)	1.80
Cycle Time Differential (sec)	.00



Bilateral Parameters	Left	Right
Step Time (sec)	.52/4.2	.53/4.6
Cycle Time (sec)	1.04/3.1	1.05/3.7
Step Length (cm)	39.44/7.9	40.78/8.5
Stride Length (cm)	81.20/6.7	80.96/6.6
H-H Base Support (cm)	9.69	9.53
Single Support (%GC)	35.2	34.4
Double Support (%GC)	30.2	30.1
Swing (%GC)	34.5	35.1
Stance (%GC)	65.5	64.9
Step/Extremity Ratio	.48	.49
Toe In / Out (deg)	11	14

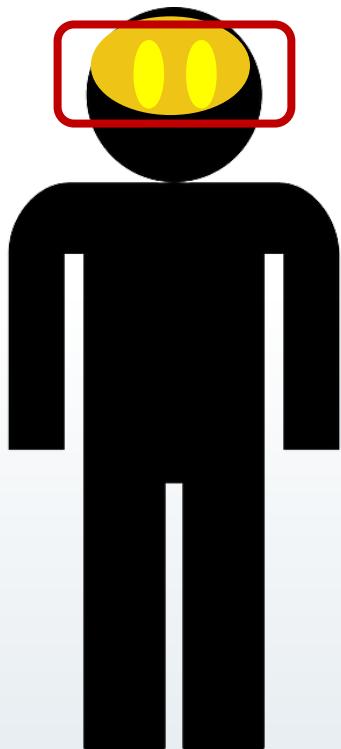
Parameters	
Distance (cm)	4171.4
Ambulation Time (sec)	54.48
Velocity (cm/sec)	76.6
Mean Normalized Velocity	.92
Number of Steps	104
Cadence (Steps/Min)	114.5
Step Time Differential (sec)	.01
Step Length Differential (cm)	1.33
Cycle Time Differential (sec)	.00

FAP Deduction From	100
Step Functions Left	-9
Step Functions Right	-8
Diff Step Extr. Ratio	
HH Dyn. Base of Supp	
Ambulatory Aids	
Assistive Devices	
FAP Score	83

Demonstration

F/73 PD

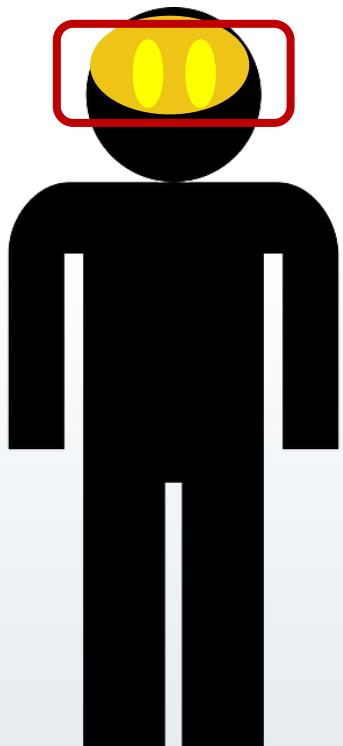
# Dyskinetic gait - dystonic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓/ =	=/↑	=/↑	=	=/↑	Dystonic posturing

- Causes: dystonia
- Bizarre gait, dystonic posturing
- Foot inversion, plantar flexion, tonic extension of big toe
- Sensory trick may improve gait
- Different motor program may improve gait
  - Backward walking or running

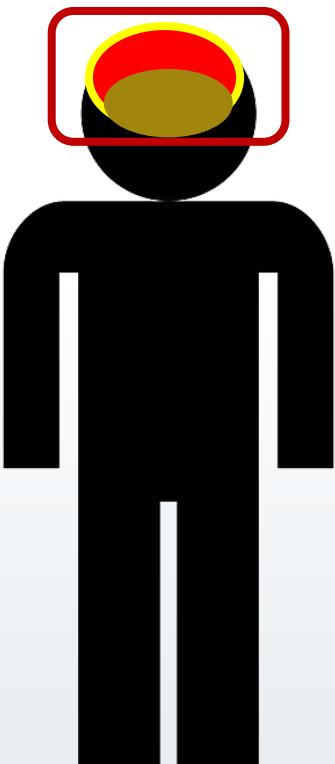
# Dyskinetic gait - choreic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓	↓/≡	=/↑	=/↑	↑	↑↑	Chorea Dancing gait

- Causes: chorea
- Bizarre **dancing gait**
- Marked increased irregularity (variability) gait parameters
- Purposeless jump, skip of steps, un-intended movement from walking direction
- Uncommon falls

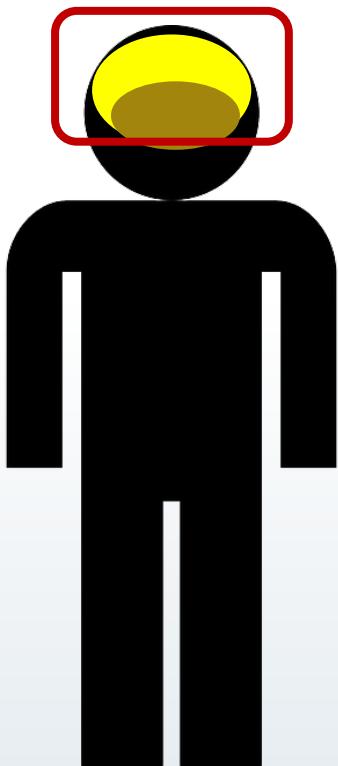
# Dyskinetic gait - myoclonic gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
=	=	=	=	=	↑	Myoclonus

- Causes: myoclonus, hypoxic ischemic encephalopathy
- Bouncing gait – positive myoclonus
- Buckling gait – negative myoclonus
  - Also common in functional gait disorder

# Higher level gait disorder (HLGD)



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓/=	↓↑	↓	↓↑	=/↑	↑↑	FOG

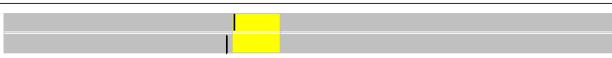
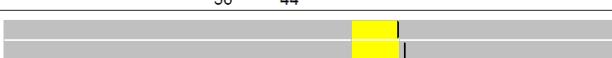
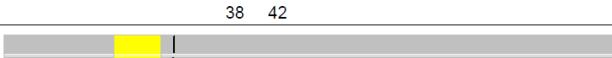
- Various terms: **frontal gait disorder, gait apraxia, gait ignition failure, subcortical disequilibrium, frontal gait disequilibrium**
- Causes: **vascular parkinsonism, normal pressure hydrocephalus, frontal dysfunction, FTLD**
- Freezing of gait, small steps, disequilibrium
- Fear of falling -> **cautious gait**

# Demonstration: HLGD

## Parameters

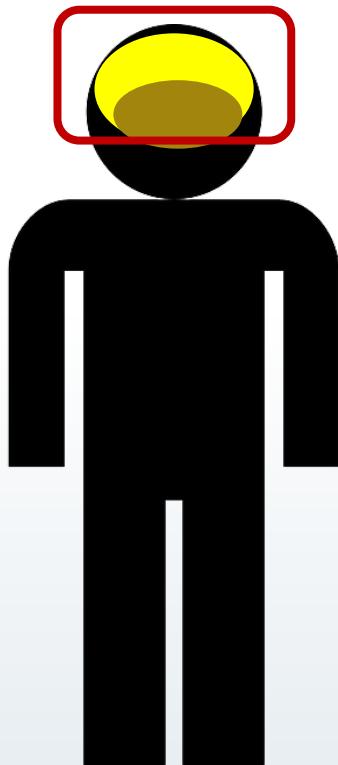
Distance (cm)	962.2
Ambulation Time (sec)	12.81
Velocity (cm/sec)	75.1
Mean Normalized Velocity	.00

Cadence (Steps/Min)	168.6
Step Time Differential (sec)	.01
Step Length Differential (cm)	1.01
Cycle Time Differential (sec)	.01

Walk # / Footfall #	L/R	Mean(%CV)	Sample Normal Values
Step Time (sec)	L	.352(8.2)	 0.53 0.59
	R	.359(7.0)	
Cycle Time (sec)	L	.708(5.9)	 1.06 1.18
	R	.717(5.9)	
Swing Time (sec) / %GC	L	.261(8.4) /36.9	 36 44
	R	.256(6.6) /35.7	
Stance (sec) / %GC	L	.447(6.5) /63.1	 56 64
	R	.461(7.2) /64.3	
Single Support (sec) / %GC	L	.256(6.6) /36.2	 38 42
	R	.261(8.4) /36.4	
Double Support (sec) / %GC	L	.193(10.9) /27.3	 16 24
	R	.195(9.2) /27.2	
Step Length (cm)	L	27.233(11.0)	 58 85
	R	26.221(9.9)	
Stride Length (cm)	L	53.314(9.0)	 116 170
	R	53.714(9.4)	
Base of Support (cm)	L	24.71(4.5)	
	R	24.76(4.5)	
Toe In / Out (deg)	L	20(0)	
	R	22(0)	

# Episodic gait disorder

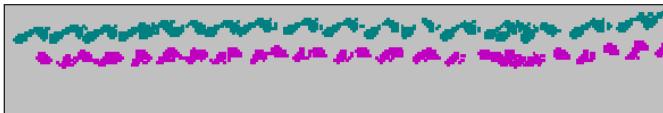
## - Freezing of gait



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
↓/ =	↑	↓	=	↓↑	↑	FOG

- Short (rarely exceeding 30 seconds), intermittent episodes of an inability to initiate or maintain locomotion or perform a turn
- Feet are “glued” to the ground
- **Provocation test: turn around (quickly)**
- Severity: small steps forward -> trembling in place -> complete immobility
- Causes: **primary progressive freezing of gait, PSP, CBS, advanced PD**

# F/69 Freezing of gait

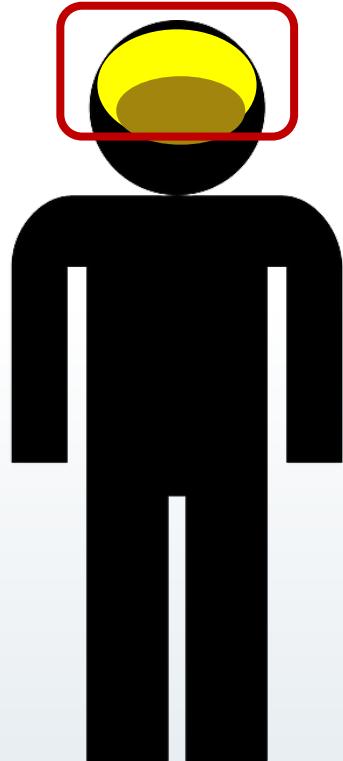


**Functional Ambulation Profile: 48**

<b>Bilateral Parameters</b>	<b>Left</b>	<b>Right</b>	<b>Parameters</b>
Step Time (sec)	.83/97.7	.58/29.7	Distance (cm) 345.6
Cycle Time (sec)	1.41/63.4	1.42/58.4	Ambulation Time (sec) 25.35
Step Length (cm)	5.47/41.0	13.73/33.6	Velocity (cm/sec) 13.6
Stride Length (cm)	19.25/27.4	19.37/32.7	Mean Normalized Velocity .15
H-H Base Support (cm)	11.58	11.60	Number of Steps 36
Single Support (%GC)	31.0	35.1	Cadence (Steps/Min) 85.2
Double Support (%GC)	36.9	32.6	Step Time Differential (sec) .25
Swing (%GC)	35.4	30.8	Step Length Differential (cm) 8.25
Stance (%GC)	64.6	69.2	Cycle Time Differential (sec) .01
Step/Extremity Ratio	.06	.15	
Toe In / Out (deg)	14	9	

FAP Deduction From	100
Step Functions Left	-22
Step Functions Right	-22
Diff Step Extr. Ratio	-8
HH Dyn. Base of Supp	
Ambulatory Aids	
Assistive Devices	
FAP Score	48

# Functional gait disorder (psychogenic gait disorder)



Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features
$\downarrow/\!=/\uparrow$	$\downarrow/\!=/\uparrow$	$\downarrow/\!=/\uparrow$	$\downarrow/\!=/\uparrow$	$\downarrow/\!=/\uparrow$	$\downarrow/\!=/\uparrow$	PSY movement

- **Bizarre gait**
- **Features of functional movement disorders (FMD)**
  - Inconsistency, incongruency, distraction
- **Generally uncommon, in association with FMD**
- **Pure functional gait: buckling gait m/c**
- **With FMD: excessive slow gait m/c**
- **More detailed descriptions in the next table**

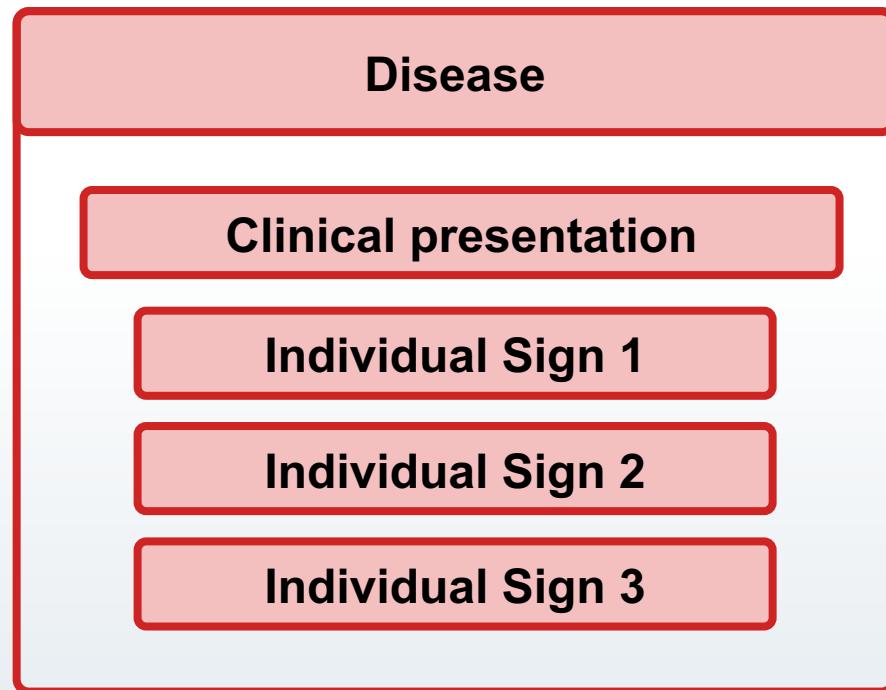
# Suggestive features of functional gait disorders

Suggestive Features	Caveats and Pitfalls
Variable, inconsistent pattern which is usually worsened when bystanders are present	Episodic weakness in myasthenia gravis, cataplexy, and paroxysmal dyskinesias
Incongruous with known gait disorders (bizarre)	Especially if consistent over time, might be caused by less-known conditions such as cataplexy, task-specific dystonic gait, or drug-induced dyskinesias
Rarely falls/injuries	Exceptions with sometimes severe injuries have been described
Momentary fluctuations of stance and gait, often in response to suggestion	
Excessive slowness (without sequence effect) or hesitation	Pyramidal slowness
"Psychogenic" Romberg test with a build-up of sway amplitudes after a silent latency or with improvement by distraction	
Nonphysiologic pattern with uneconomic postures and wastage of muscular energy	Dystonia
"Walking on ice" gait pattern (small, cautious steps with fixed ankle joints)	Cautious gait is often the presenting feature of organic diseases (eg, stiff person syndrome or orthostatic tremor)
Sudden buckling of the knees, usually without falling (the most common type of pure psychogenic gait disorder)	
Abrupt onset	Stroke, etc
Incongruous affect (la belle indifference)	Not easily assessable
Secondary gain	Not easily assessable, especially with long disease duration
Prior or actual history of psychiatric disease	Common in many organic conditions (eg, dementia), "fear of falling" in case of balance disorders

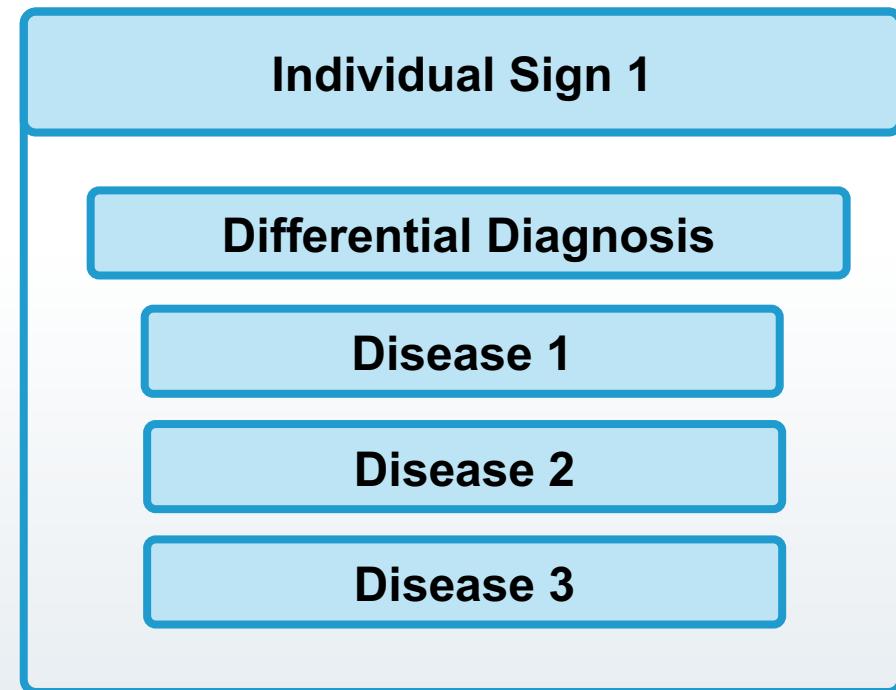
Level	Anatomic level	Gait disorder	Velocity	Cadence	Step length	Asymmetry	Step width	Variability	Additional features	Etiology
Lower	Orthopedic	Antalgic gait	↓	↓	↓	↑↑	=	↑	Limping	Distal orthopedic diseases knee osteoarthritis, ankle sprain, foot fracture
		Coxalgic gait	↓	↓	↓	↑↑	=	↑	Limping Truncal lurch	Hip osteoarthritis
	Neuromuscular (peripheral)	Waddling gait	↓/=	↓/=	↓/=	=	=	=/↑	Usually bilateral Trendelenburg sign	Pelvic girdle, proximal muscle weakness, myopathy
		Steppage gait	↓/=	↓/=	↓↑	=/↑	=	=/↑	Foot-drop Drag-to gait	Distal muscle weakness, neuropathy
Intermediate	Spinal cord	Spastic gait (para-paretic)	↓	↓	↓	=/↑↑	↓/=/↑	↑	Weakness Scissoring	Hemiparesis or paraparesis
		Sensory ataxic gait	↓	↓	=/↑	=	↑↑	↑	Dysmetria Romberg sign Staggering	Proprioceptive dysfunction, sensory polyneuropathy, dorsal column lesions
	Brain	Spastic gait (para- or hemiparetic)	↓	↓	↓	=/↑↑	↓/=/↑	↑	Weakness Circumduction Scissoring	Hemiparesis or paraparesis
		Ataxic gait								
		Sensory ataxic gait	↓	↓	=/↑	=	↑↑	↑	Dysmetria, Romberg sign, Staggering	Proprioceptive dysfunction
		Cerebellar ataxic gait	↓	↓	=/↑	=	↑↑	↑	Ataxia, Staggering	Cerebellar ataxia
		Vestibular ataxic gait	↑	↑	=/↑	=	=/↑	↑	Nystagmus, N/V, Staggering	Unilateral / bilateral vestibulopathy, Meniere disease
		Bradykinetic/hypokinetic gait	↓	↑	↓	↑	↓/=	↑	Parkinsonism, Flexed posture, Shuffling	Parkinson's disease, other Parkinson syndrome
		Dyskinetic gait								
		Dystonic gait	↓	↓/=	=/↑	=/↑	=	=/↑	Dystonic posturing	Dystonia
		Choreic gait	↓	↓/=	=/↑	=/↑	↑	↑↑	Chorea, Dancing gait	Chorea
		Myoclonic gait	=	=	=	=	=	↑	Myoclonus	Positive / negative myoclonus
Higher	Brain	Higher level gait disorder	↓/=	↓↑	↓	↓↑	=/↑	↑↑	FOG	Vascular parkinsonism, normal pressure hydrocephalus, frontal dysfunction, FTLD
		Freezing of gait	↓/=	↑	↓	=	↓↑	↑	FOG	primary progressive freezing of gait, PSP, advanced PD, HLGD
Misc.		Functional gait disorder	↓/=/↑	↓/=/↑	↓/=/↑	↓/=/↑	↓/=/↑	↓/=/↑	Functional movement disorders	Functional movement disorders

# Approach to gait disorders

## Classic approach



## Sign-based approach



**Both approaches are necessary!**

# Summary

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- **Phenomenology of gait disorders**
  - Causes of gait disorders include neurological, orthopedic, and psychiatric conditions (+medical conditions).
  - Multifactorial etiology becomes more common with advancing age.
- **Clinical application of instrumental gait analysis**
  - Spatiotemporal gait parameters are often overlapped among different gait disorders and various within one disease.
  - Instrumental gait analysis require further validation for differential diagnosis of gait disorders.
  - Still, it has possible roles for mild gait impairments, follow-up, or measuring treatment response
- **Detailed history taking, neurological examination, and both classic and sign-based approaches are mandatory to diagnose patients with gait disorders.**
  - especially in patients with complex gait features.

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Thank you for your attention!!!

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