

	Al-Mustaqbal University / College of Engineering	
	Prosthetics & Orthotics Eng. Department	
	Third Class	
	Subject (Biomechanics II)	
	Code (POER314)	
	Asst. Lec. Mariam Ghassan Al-marroof	
	1 <sup>st</sup> term – Lecture 2	

## *The Three-Dimensional and Cyclic Nature of Gait, Periodicity of Gait, Parameters of Gait.*

Figure 2.1, that explains the three primary planes of the human body:

- **Sagittal Plane** (divides the body into right and left)
- **Frontal (Coronal) Plane** (divides the body into front and back)
- **Transverse Plane** (divides the body into upper and lower)

This figure demonstrates that human movement, including gait, occurs in three dimensions.

- In the **sagittal plane**, flexion and extension dominate (hip, knee, ankle motion during walking).
- In the **frontal plane**, lateral stability is controlled (pelvic drop, hip abduction).
- In the **transverse plane**, rotational movements occur (pelvic rotation, limb rotation).

Although the sagittal plane is probably the most important one, where much of the movement takes place (see Figure 2.2, a), there are certain pathologies where another plane (e.g., the coronal, in the case of bilateral hip pain) would yield useful information (see Figure 2.2, a-c) have considered the three-dimensional nature of human gait, but they have looked at the human walker from two or three separate



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

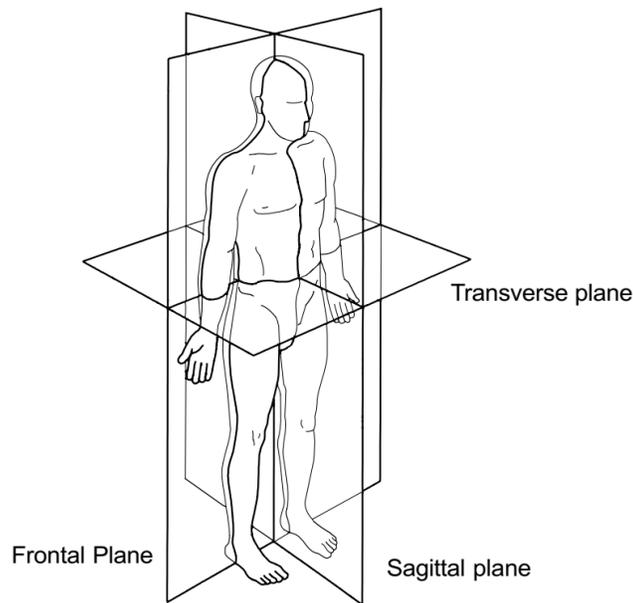
Third Class

Subject (Biomechanics II)

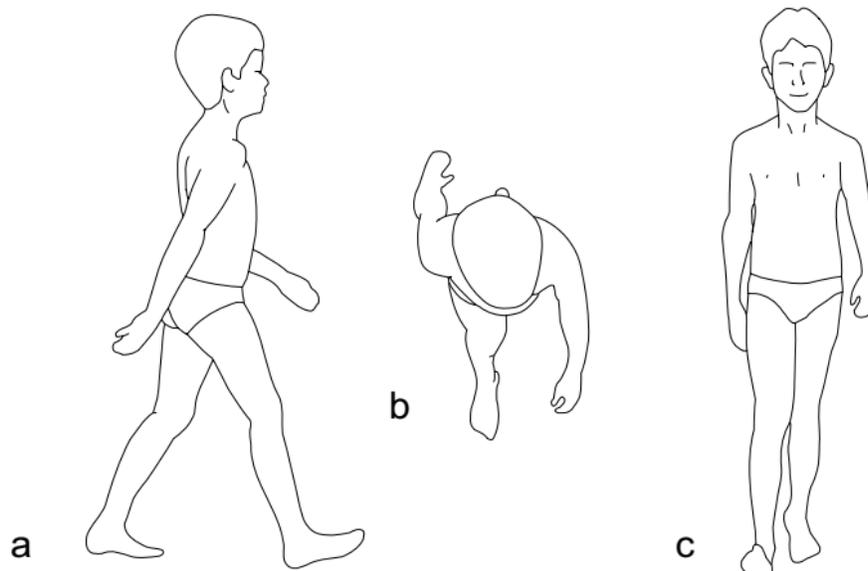
Code (POER314)

Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



**Figure 2.1** The reference planes of the human body in the standard anatomical position.



**Figure 2.2** The gait of an 8-year-old boy as seen in the three principal planes: (a) sagittal; (b) transverse; and (c) frontal.



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

Third Class

Subject (Biomechanics II)

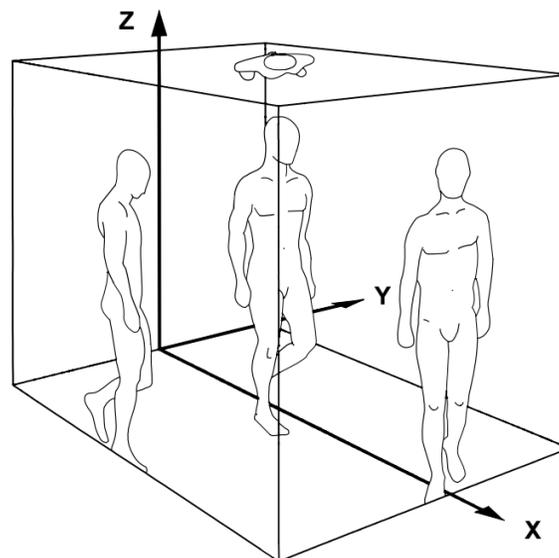
Code (POER314)

Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



views (see Figure 2.3). Though this is clearly an improvement, we believe that the analysis of human gait should be truly three-dimensional: The three separate projections should be combined into a composite image, and the parameters expressed in a body-based rather than laboratory-based coordinate system.



**Figure 2.3** The walking subject projected onto the three principal planes of movement. Note.

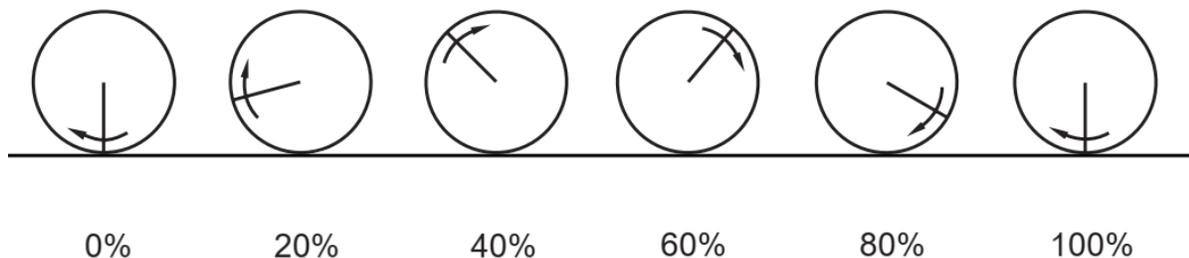
### *Periodicity of Gait*

The act of walking has two basic requisites:

1. Periodic movement of each foot from one position of support to the next
2. Sufficient ground reaction forces, applied through the feet, to support the body

	Al-Mustaqbal University / College of Engineering	
	Prosthetics & Orthotics Eng. Department	
	Third Class	
	Subject (Biomechanics II)	
	Code (POER314)	
	Asst. Lec. Mariam Ghassan Al-marroof	
1 <sup>st</sup> term – Lecture 2		

Figure 2.4 illustrates the movement of a wheel from left to right. In the position at which we first see the wheel, the highlighted spoke points vertically down. (The wheel is not stationary here; a **snapshot** has been taken as the spoke passes through the vertical position.) By convention, the beginning of the cycle is referred to as 0%. As the wheel continues to move from left to right, the highlighted spoke rotates in a clockwise direction. At 20% it has rotated through  $72^\circ$  ( $20\% \times 360^\circ$ ), and for each additional 20%, it advances another  $72^\circ$ . When the spoke returns to its original position (pointing vertically downward), the cycle is complete (this is indicated by 100%).



**Figure 2.4** A rotating wheel demonstrates the cyclic nature of forward progression.



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

Third Class

Subject (Biomechanics II)

Code (POER314)

Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



## Gait Cycle

A gait cycle is defined as: The interval between two successive initial contacts of the same foot.

The cycle is expressed as a percentage:

- 0% = Initial Contact
- 100% = Next Initial Contact

The gait cycle consists of two major phases:

- Stance Phase (~60%)

The foot is in contact with the ground.

Subdivisions:

- First Double Support
- Single Limb Support
- Second Double Support

- Swing Phase (~40%)

The foot is not in contact with the ground and advances forward.

	Al-Mustaqbal University / College of Engineering	
	Prosthetics & Orthotics Eng. Department	
	Third Class	
	Subject (Biomechanics II)	
	Code (POER314)	
	Asst. Lec. Mariam Ghassan Al-marroof	
	1 <sup>st</sup> term – Lecture 2	

## Functional Subdivisions of the Gait Cycle

The cycle is divided into eight functional periods:

1. **Initial Contact (0%)**
2. **Loading Response (0–10%)**
3. **Midstance (10–30%)**
4. **Terminal Stance (30–50%)**
5. **Preswing (50–60%)**
6. **Initial Swing (60–70%)**
7. **Midswing (70–85%)**
8. **Terminal Swing (85–100%)**

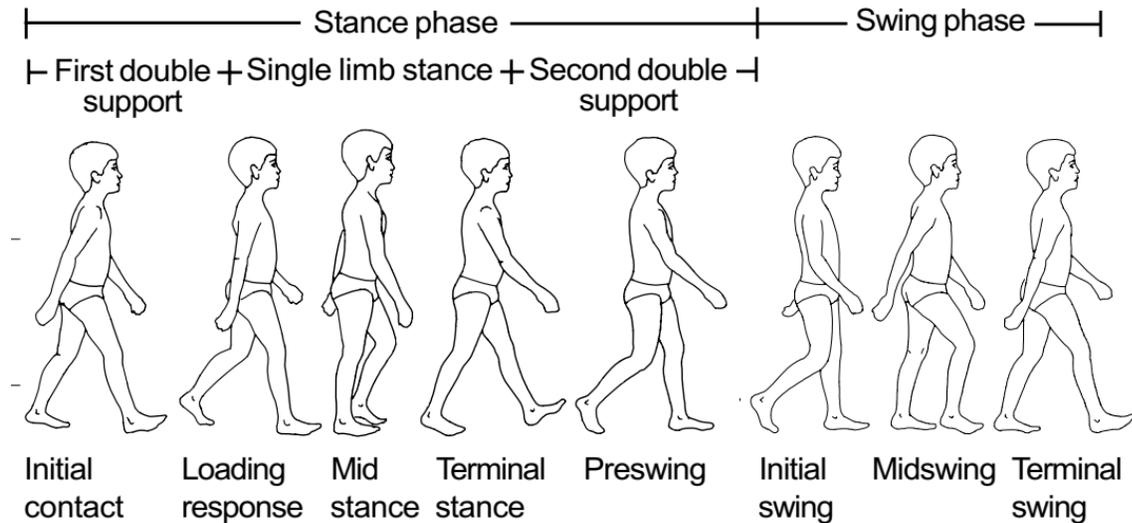
Each phase corresponds to a specific mechanical objective:

- Weight acceptance
- Single limb support
- Limb advancement

This structure describes the functional role of the limb during walking

Figure 2.5 illustrates a single cycle for a normal 8- year-old boy. Note that by convention, the cycle begins when one of the feet (in this case the right foot) makes contact with the ground.

	Al-Mustaqbal University / College of Engineering	
	Prosthetics & Orthotics Eng. Department	
	Third Class	
	Subject (Biomechanics II)	
	Code (POER314)	
	Asst. Lec. Mariam Ghassan Al-marroof	
1 <sup>st</sup> term – Lecture 2		



**Figure 2.5** The normal gait cycle of an 8-yearold boy.

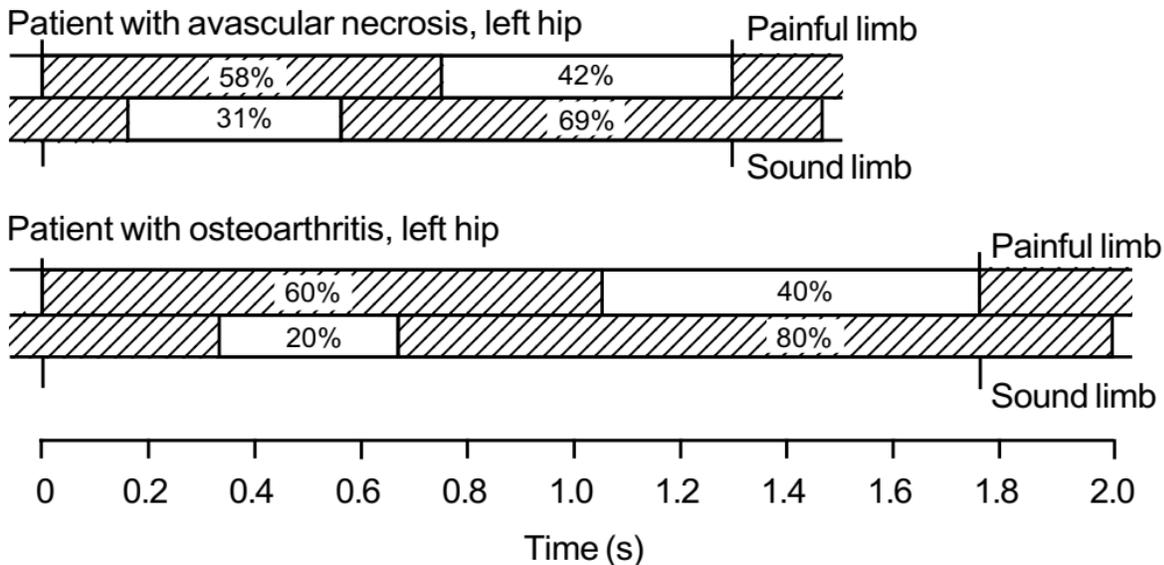
Note that though the nomenclature in Figure 2.5 refers to the right side of the body, the same terminology would be applied to the left side, which for a normal person is half a cycle behind (or ahead of) the right side. Thus, first double support for the right side is second double support for the left side, and vice versa. In normal gait there is a natural symmetry between the left and right sides, but in pathological gait an asymmetrical pattern very often exists. This is graphically illustrated in Figure2.6.

### Pathological:

- Reduced stance time on painful limb
- Increased stance on sound limb
- Increased total cycle time

	Al-Mustaqbal University / College of Engineering	
	Prosthetics & Orthotics Eng. Department	
	Third Class	
	Subject (Biomechanics II)	
	Code (POER314)	
	Asst. Lec. Mariam Ghassan Al-marroof	
1 <sup>st</sup> term – Lecture 2		

Mechanical interpretation: The patient reduces load duration on the painful side



**Figure 2.6** The time spend on each limb during the gait cycle of a normal man and two patients with unilateral hip pain

Traditionally the gait cycle has been divided into eight events or periods, five during stance phase and three during swing. The names of these events are self-descriptive and are based on the movement of the foot, as seen in Figure 2.7. In the traditional nomenclature, the stance phase events are as follows:

1. Heel strike initiates the gait cycle and represents the point at which the Body's center of gravity is at its lowest position.
2. Foot-flat is the time when the plantar surface of the foot touches the ground.
3. Midstance occurs when the swinging (contralateral) foot passes the stance foot and the body's Centre of gravity is at its highest position.
4. Heel-off occurs as the heel loses contact with the ground and pushoff is



initiated via the triceps surae muscles, which plantar flex the ankle.

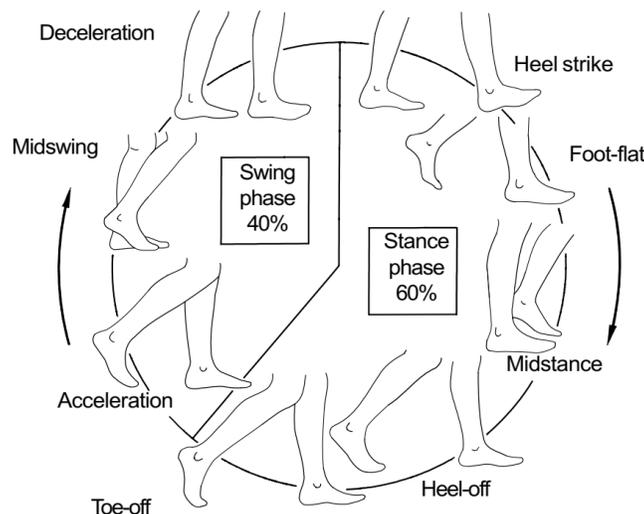
5. Toe-off terminates the stance phase as the foot leaves the ground

**The swing phase events are as follows:**

6. Acceleration begins as soon as the foot leaves the ground and the subject activates the hip flexor muscles to accelerate the leg forward.

7. Midswing occurs when the foot passes directly beneath the body, coincidental with midstance for the other foot.

8. Deceleration describes the action of the muscles as they slow the leg and stabilize the foot in preparation for the next heel strike



**Figure 2.7** The traditional nomenclature for describing eight main events, emphasizing the cyclic nature of human gait.



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

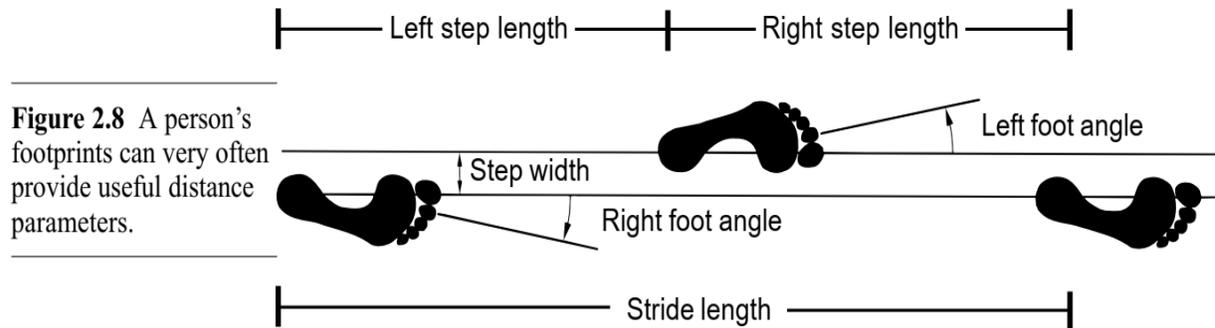
Third Class

Subject (Biomechanics II)

Code (POER314)

Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



**Figure 2.8** A person's footprints can very often provide useful distance parameters.

- **Stride Length:** Distance between two heel strikes of the same foot.
- **Step Length:** Distance between opposite feet.
- **Step Width:** Mediolateral separation between feet.
- **Foot Angle:** Orientation relative to progression line.

Increased step width suggests impaired balance.

Another useful parameter shown in Figure 2.8 is step width, which is the medio lateral distance between the feet and has a value of a few centimeters for normal subjects.

For patients with balance problems, such as cerebellar ataxia or the athetoid form of cerebral palsy, the stride width can increase to as much as 15 or 20 cm

	Al-Mustaqbal University / College of Engineering	
	Prosthetics & Orthotics Eng. Department	
	Third Class	
	Subject (Biomechanics II)	
	Code (POER314)	
	Asst. Lec. Mariam Ghassan Al-marroof	
	1 <sup>st</sup> term – Lecture 2	

Finally, the angle of the foot relative to the line of progression can also provide useful information, documenting the degree of external or internal rotation of the lower extremity during the stance phase.

### Parameters of Gait

The cyclic nature of human gait is a very useful feature for reporting different parameters. As you will later discover in GaitLab, there are literally hundreds of parameters that can be expressed in terms of the percent cycle. We have chosen just a few examples (displacement, ground reaction force, and muscle activity) to illustrate this point.

### Displacement

Figure 2.9 shows the position of a normal male's right lateral malleolus in the Z (vertical) direction as a function of the cycle. At heel strike, the height is about 0.07 m, and it stays there for the next 40% of the cycle because the foot is in contact with the ground.



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

Third Class

Subject (Biomechanics II)

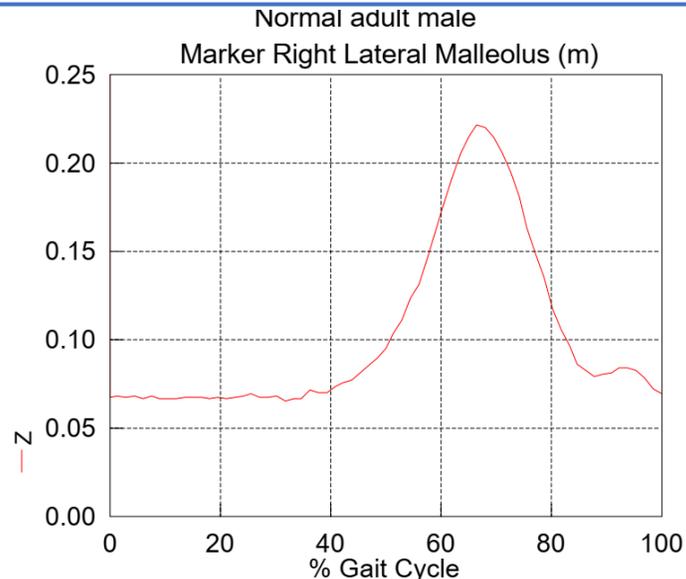
Code (POER314)

Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



**Figure 2.9** The height (value in the Z direction) in metres (m) of a normal male's right malleolus as a function of the gait cycle.



Then, as the heel leaves the ground, the malleolus height increases steadily until right toe-off at about 60%, when its height is 0.17 m. After toe-off, the knee continues to flex, and the ankle reaches a maximum height of 0.22 m at 70% of the cycle. Thereafter, the height decreases steadily as the knee extends in preparation for the following right heel strike at 100%. This pattern will be repeated over and over, cycle after cycle, as long as the subject continues to walk on level ground.

## Ground Reaction Force

Figure 2.10 shows the vertical ground reaction force of a cerebral palsy adult as a function of the gait cycle.

Shortly after right heel strike, the force rises to a value over 800 newtons (N) (compared to his weight of about 700 N). By midswing this value has dropped to 400 N, which is a manifestation of his lurching manner of walking. By the beginning of the second double support phase (indicated by LHS, or left heel strike), the vertical force is back up to the level of his body weight. Thereafter it decreases to zero when right toe-off occurs. During the swing phase from right toe-off to right heel strike, the force obviously remains at zero. This ground reaction force pattern



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

Third Class

Subject (Biomechanics II)

Code (POER314)

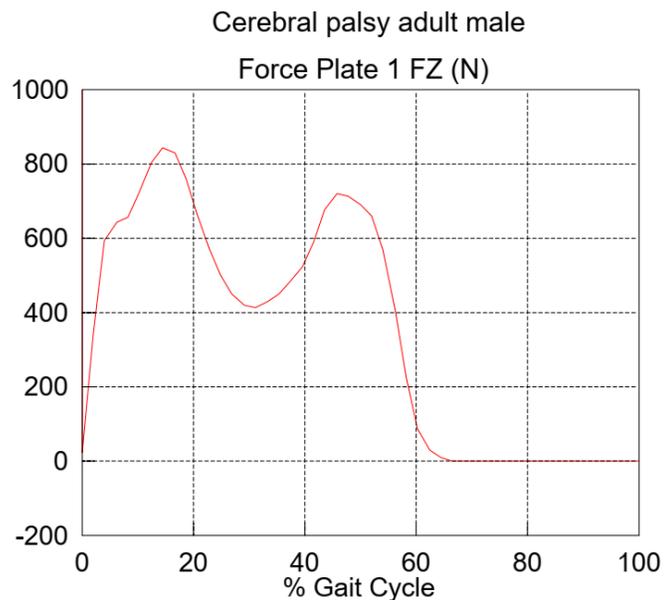
Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



is quite similar to that of a normal person except for the exaggerated drop during midstance.

**Figure 2.10** The vertical ground reaction force in newtons (N) acting on a cerebral palsy adult's right foot during the gait cycle.



## Muscle Activity

Muscle activity, too, can be plotted as a function of percent cycle as seen in Figure 2.11. Here the EMG of the rectus femora's for a normal female is illustrated. Notice that just after right heel strike, the EMG increases. Because the rectus femora's is a hip flexor and knee extensor, but the hip and knee are extending and flexing at this time, the muscle is acting eccentrically. During the midstance phase, the activity decreases substantially, picking up again during late stance and early swing. During this period, both the hip and knee are flexing. The rectus femora's is again



Al-Mustaqbal University / College of Engineering

Prosthetics & Orthotics Eng. Department

Third Class

Subject (Biomechanics II)

Code (POER314)

Asst. Lec. Mariam Ghassan Al-marroof

1<sup>st</sup> term – Lecture 2



reasonably quiescent in midswing, but its activity increases before the second right heel strike.

**Figure 2.11** The electromyographic activity in microvolts ( $\mu\text{V}$ ) of a normal female's right rectus femoris muscle plotted as a function of the gait cycle.

