Appendix 7 Gait analysis

The precise elements of gait analysis vary slightly between institutions. Gait analysis at Gillette includes the following:

- Medical history
- X-rays
- Parent (or individual)-reported functional questionnaires
- Two-dimensional video
- A standardized physical examination
- Three-dimensional computerized motion analysis (3D computerized motion analysis)
    - Kinematics: 3D measurement of motion (movement)
    - Kinetics: 3D measurement of forces and mechanisms that cause motion
- Electromyography (EMG): Measurement of the activity of muscles
- Pedobarography: Measurement of the pressure distribution under the feet
- Energy expenditure: Measurement of the energy used during walking

A typical gait analysis lasts about 2 ½ - 3 hours. However, it is broken down into the various elements listed above, none of which takes very long. The longest portion is usually the physical examination.

2 ½-3 hours is a long time for a small child to remain cooperative. It is important to make sure that the child is well-rested and well-fed before the appointment; having a snack or drink on hand to keep up their energy during the long appointment can be helpful. The gait lab usually specifies the type of clothing to wear, for example, loose-fitting shorts with an elastic waist and a tank top for girls and loose-fitting shorts for boys. Any orthoses and walking aids (e.g., crutches, walkers, or canes) that the person uses should also be brought.

The gait laboratory where gait analysis is carried out has a special walkway about 20 meters long, with special plates in the floor over which the person walks. The plates measure the forces produced as the person walks. There are also cameras around the room.

The following details the different elements of gait analysis at Gillette and is a useful guide to gait analysis at most centers. You may find it helpful to refer back section 2.5 on normal walking as you read this.

Medical history
Medical history includes information on:
- Birth history
- Developmental milestones
- Any medical problems
- Surgical history
- Current PT program
- Current medications
- Parent (or individual) report on functional walking at home, school, and in the community and other functional skills (e.g., climbing stairs, running, and jumping)
- Any complaints of pain
- Any behavioral or learning issues
- Reason for referral to gait lab, including current surgical or treatment considerations
- Goals for treatment

Parent (or individual)-reported functional questionnaires
At Gillette, the following are completed:
- To measure function in the community
    - Gillette Functional Assessment Questionnaire (FAQ), Walking Ability and Higher-Level Functional Skills

  - Pediatric Outcomes Data Collection Instrument (PODCI)
  - Gait Outcomes Assessment List Questionnaire (GOAL)
- To measure goals:
  - Gait Outcomes Assessment List Questionnaire (GOAL).

(Details of the above measurement tools are included in Appendix 3).

Two-dimensional video

This visual record is useful for understanding a person's gait problems and for comparing gait before and after treatment. The information obtained by observing the person walk complements the information obtained from the 3D computerized motion analysis equipment. It is useful to see how the child walks without any of the marker equipment used in 3D computerized motion analysis. Any problems with posture and balance in standing and walking are also noted. See figure A.7.1.

Figure A.7.1 Two-dimensional video

A standardized physical examination

The following are typically measured in the physical examination:

- Muscle strength
- Selective motor control
- Muscle tone
- Range of motion and contractures
- Bone deformity
- Fixed and mobile foot deformities
- Leg length
- Extensor lag (Extensor lag is the difference between the active and passive knee extension)
- Ligament laxity (loose ligaments)

Gait laboratories usually have very standard protocols for completing each.

Three-dimensional computerized motion analysis (3D computerized motion analysis)

3D computerized motion analysis provides a very detailed analysis of walking. The motion-capturing equipment used in 3D computerized motion analysis is the same technology used for animation in the film and video game industries. The clinician, usually a physical therapist, applies small markers to the person's body at specific points. Figure A.7.2 shows the therapist putting on these markers.

Figure A.7.2 Applying the markers for 3D computerized motion analysis

As a person walks, many changes occur at different joints in the body and in different planes. In addition to the many changes that occur in normal walking, the person with spastic diplegia has a combination of primary, secondary, and tertiary abnormalities that interfere with their walking. The speed of these changes as the person walks is far greater than the speed at which the observer can process the changes. The cameras capture the markers at high speed (120 frames per second at Gillette; 200 frames per second at the CRC[1]). The equipment provides far more information than can be gleaned from even a very experienced eye (four to seven times faster than can be seen by eye) or from watching slow-motion videotape (which captures images at 30 frames per second). The information from the cameras is synchronized with information from the force plates and muscle activity so that all of the data is collected simultaneously.

The 3D computerized motion analysis output allows the staff to compare the person's walking pattern with data collected from normal walking. Differences in the person's walking pattern are identified and a list of deviations drawn up.

The following describes how Gillette displays gait data; other gait laboratories may produce them slightly differently.

- **Kinematics**

Kinematics is the quantitative three-dimensional measurement of motion (movement). Kinematics show what is happening at the trunk, pelvis, hip, knee, and ankle on both sides of the body and in all three planes of motion. The kinematic graphs show the position and pattern of each body segment at each point in the gait cycle. See figure A.7.3.

[1] Central Remedial Clinic in Dublin.

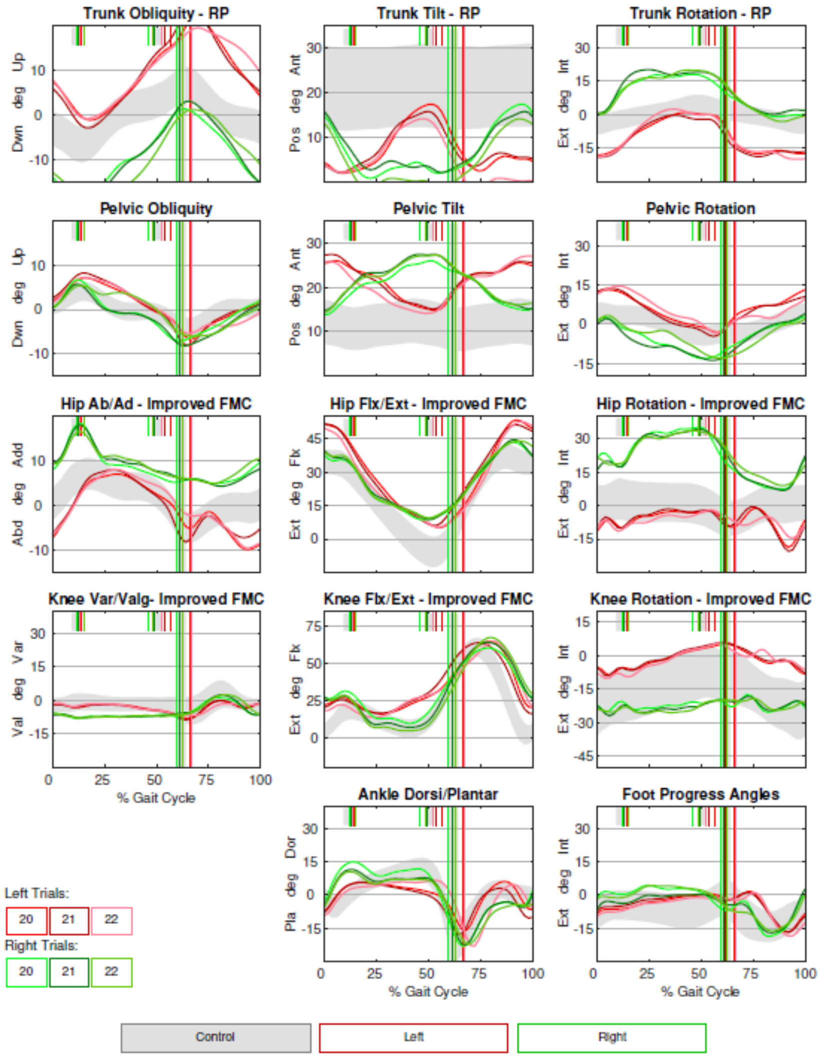

Figure A.7.3 Kinematic graphs

The horizontal axis of all graphs represents one full gait cycle. The shaded areas in the graph show the gait patterns of typically developing children. The area left of the vertical line represents when the foot is on the ground (stance phase, approximately 60 percent of the gait cycle); the area to the right represents when the foot is in the air (swing phase). The right lower limb is labeled green, and the left is labeled red. The graphs for both legs are synchronized and therefore are not happening at the same time.

The five rows represent the trunk, pelvis, hip, knee, and ankle, respectively.

The three columns represent the three planes of motion. From left to right, they are:

- From the back or front: the coronal plane.
- From the side: the sagittal plane
- From the top or bottom: the transverse plane.

When looking at kinematics, the points to note are how well the person's graphs (green and red) match normal gait (the shaded area). Does the shape (pattern and position) of the graph for each limb match normal gait? Is the timing of events within the gait cycle (e.g., stance and swing time) normal?

- **Kinetics**

Kinetics help to explain the movement seen in the kinematic graphs. Kinetic data is obtained from the special plate data combined with kinematics. See figure A.7.4.

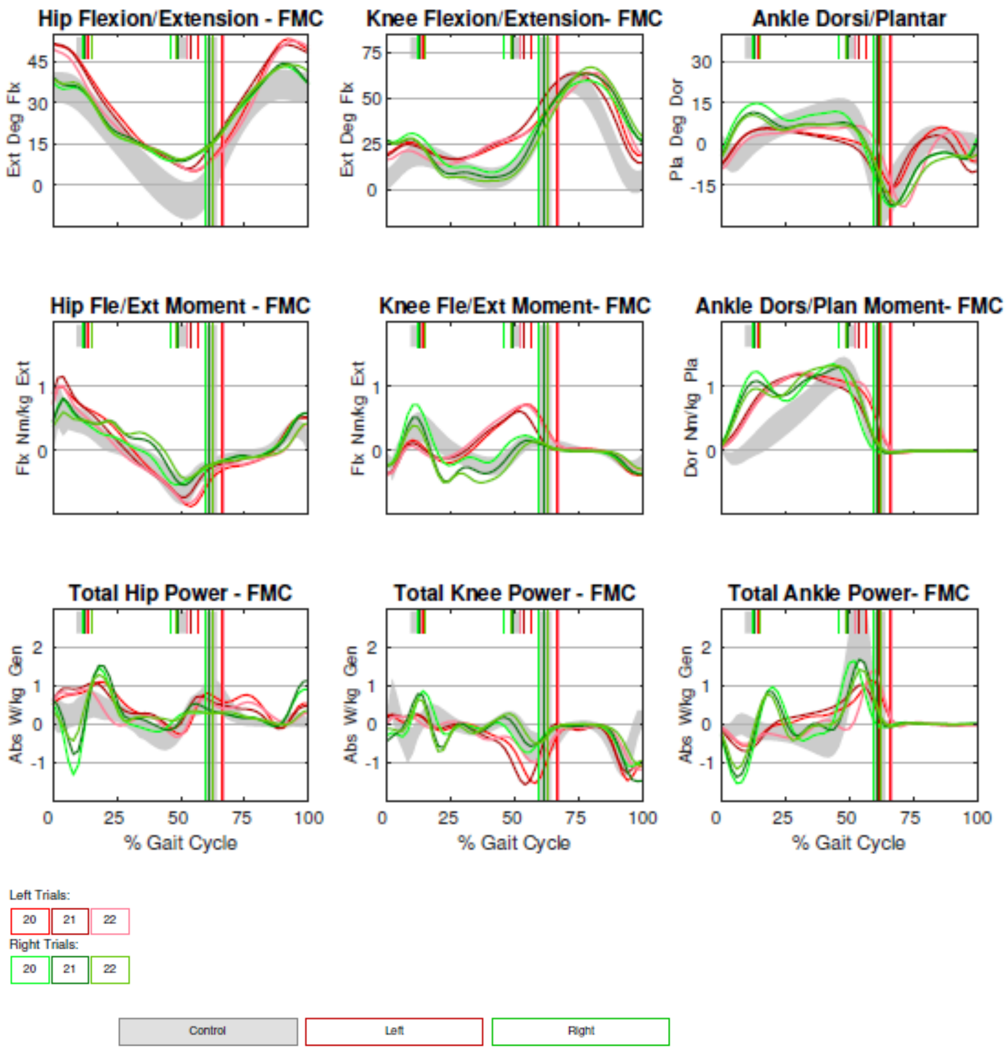

Figure A.7.4 Kinetic graphs

The kinetic graphs show:

- First row: The person's kinematic graphs at hip, knee, and ankle level—i.e., what is happening during the gait cycle. (These are just included for reference.)
- Second row: The moments generated at these joints during the gait cycle. (Remember, a moment is a force [e.g., a muscle contraction] acting on a lever [i.e., the bone] about a joint, which produces movement.)
- Third row: Power at these joints (a combination of how fast the joint is moving and the moment being produced) during the gait cycle.

The moment (second row) and power (third row) graphs provide information about the cause of gait abnormalities—the "why" that explains the "what" of the kinematics (first row).

Again, when looking at kinetics, the points to note are how well the person's graphs (green and red) match normal gait (the shaded area). Does the shape (pattern and position) of the graph for each limb match normal gait? Is the timing of events within the gait cycle (e.g., stance and swing time) normal?

Kinetic graphs are generated in two planes–the coronal and sagittal planes. The graphs shown are from the sagittal plane.

Electromyography (EMG)

Electromyography (EMG) is the measurement of the electrical activity of the muscles.[2] It provides information about the amount of muscle activity. There are times in the gait cycle when a muscle is supposed to be working and times when it is supposed to be silent. A typical EMG graph is displayed in figure A.7.5.

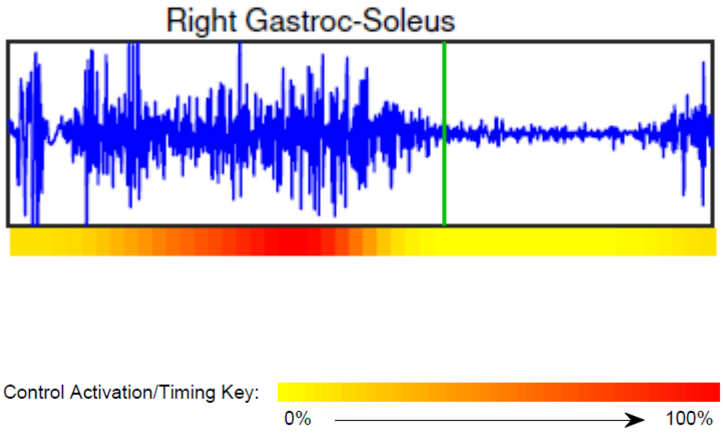

Figure A.7.5 EMG graph

As always, the person's graph is compared with normal gait. The colored bars underneath the graph show the normal pattern: yellow when the muscle is silent and reddest when it is most active. The blue line shows when the muscle is contracting and when it is not. It shows that this muscle is not working correctly because it comes on earlier than it should at the beginning of the gait cycle and lasts a little longer. Also the muscle is active at the end of the gait cycle when it should be silent.

In addition to looking at activity patterns in individual muscles, activity patterns between muscles are also assessed to see how groups of muscles are working together. Some muscles are expected to work together, while others are expected to work opposite each other. While one of the agonist-antagonist pair (which we addressed in section 2.4) is working, the other is expected to be silent. (The gastrocnemius and the tibialis anterior are an example of an agonist-antagonist pair.)

Information from EMG is thus used to look for signs of spasticity—whether muscles are turning on and off at appropriate times. It also checks to see if they are working all together or all on or off at the same time—signs of patterned movement that indicate poor selective motor control. The EMG graphs are studied in conjunction with the kinematic and kinetic graphs.

Pedobarography

Pedobarography is the study of pressures underneath the foot. The person walks across a special mat that senses the pattern and distribution (high or low) of pressure under the feet. It is dynamic because it captures this information while the person is walking. (One often sees this type of technology used in sports shops for selling running shoes.) See figure A.7.6.

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Electroencephalogram (EEG) is the measurement of the electrical activity of the brain.
Electrocardiogram (ECG) is the measurement of the electrical activity of the heart.
Electromyogram (EMG) is the measurement of the electrical activity of skeletal muscle.

Figure A.7.6 Testing foot pressure

Figure A.7.7 shows plantar pressure graphs of a person's left and right sides. The colors indicate the magnitude of the pressure: red indicates high pressure and blue indicates low pressure. Once again, any deviations from the normal pattern distribution of pressure under the feet are noted. In this example, the person only bears weight on the ball of their right foot.

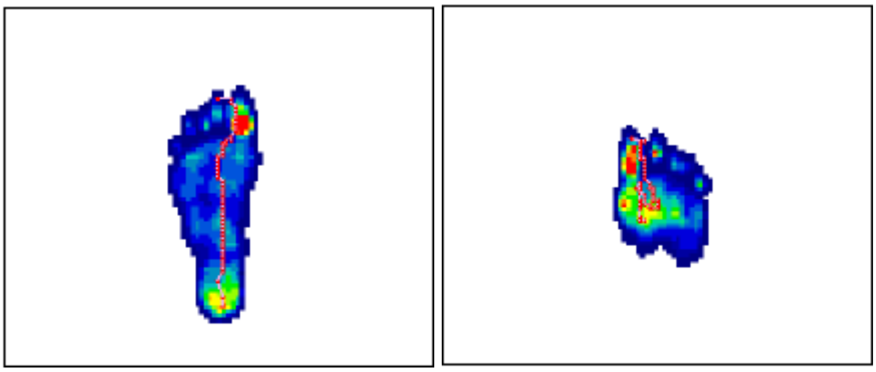

Figure A.7.7 Plantar pressure graphs of a person's left and right sides

Energy expenditure
As a result of the deviations in their gait, people with spastic diplegia frequently walk in a manner that is less energy efficient than normal walking. This test provides an objective measure of the person's energy efficiency during walking.

The person wears a mask that covers their nose and mouth, and the equipment measures the amount of oxygen they inhale and carbon dioxide they exhale. This data reveals how much energy is required to walk. Once equipped, the person first sits for 10 minutes (to measure their resting energy expenditure), then they walk for six minutes (to measure their movement energy expenditure). See figure A.7.8.

Figure A.7.8 Measuring energy expenditure

In the absence of this equipment, some gait labs use a timed walk test as an indirect indicator of the energy efficiency of walking.