Invited article

Gait analysis through sound

Kaoru Abe

Graduate School of Health and Welfare, Niigata University of Health and Welfare, Niigata, Japan

Key words: gait analysis, sound, leg-length discrepancy

Accepted: 10 May 2016

Abstract

Gait analysis in clinical practice begins with observation. When abnormalities are detected at this stage, more detailed data are collected through assessments using measurement instruments. Clinical observation is extremely important, as a wide range of information can be obtained. Assessments are conducted through visual observation, and key features to be noted have already been published and used extensively. Clinicians also notice abnormalities in gait sound; however, publications on this subject are yet to be published. This paper has been prepared based on the author's clinical experiences and describes the information that can be obtained from sounds created during the gait cycle.

1. Introduction

Gait analysis is essential in assessing abnormal and pathological gait, as information on identifying and addressing the various causes could be obtained. In clinical practice, a clinician is required to make assessments on many patients within a limited amount of time and, in fact, it is often not possible to conduct gait analysis using measurement instruments. Therefore, the assessors must rely on their own judgment when conducting gait analysis of a patient. Visual and auditory senses are used to make this judgment. Publications [1] on gait analysis through observation already exist. Workshops have been organized in Japan and attended by many participants. While the concept is routinely familiar to clinicians, research papers or publications summarizing gait analysis focusing on footstep sounds during gait are yet to be published. Through involvement in clinical practice and in the research of gait analysis over a number of years, the author values the effectiveness of sound in gait analysis along with gait analysis through observation. For instance, surely one has had the experience of being able to tell which colleague is approaching by just listening to the footsteps. The sounds that we hear, such as the dragging-shoe sound, asymmetrical footsteps and high- or low-frequency sounds, contain much information about gait. Based on the author's clinical experiences, this paper describes the diagnostic information that can be gathered from sounds at each phase of the gait cycle.

2. Gait Cycle

While walking is a full-body movement that involves many bodily functions, primarily it is the foot that makes the sound when it comes into contact with the ground. Therefore, the kinematics of the foot and ankle joint during gait will be the focus.

Corresponding author: Kaoru Abe
Graduate School of Health and Welfare, Niigata University of Health and Welfare, 1398 Shimami-cho, Kita-ku, Niigata 950-3198, Japan
TEL/FAX: +81-25-257-4525, E-mail: kao-abe@nuhw.ac.jp

The time fraction of the gait cycle consists of the stance phase, the swing phase, and the partial overlap of these phases, the double-support phase. Traditionally, the stance phase has been described as follows: heel contact (HC) → foot flat (FF) → mid stance (MS) → heel off (HO) → toe off (TO). However, this description applies to people with normal gait, and initial contact may not be HC in apoplexy hemiplegia patients with talipes equinovarus, for instance, as they first contact the ground with the toes. To address this issue, J. Perry proposed the following description to accommodate both normal and pathological gait [2]: initial contact (IC) → loading response (LR) → mid stance (MSt) → terminal stance (TSt) → pre-swing (PSw). This is known as the Rancho Los Amigos National Rehabilitation Center (RLANRC) Observational Gait Analysis System [1].

As many patients in the clinical setting exhibit pathological gait, this RLANRC system is widely used. Various conditions are presented depending on the underlying cause of the pathological gait, and its degree changes with the progression of the illness. While a distinctive gait will be observed if the disability is fixed, depending on the degree of the disability, a complicated gait will be present. There are cases where gait analysis is conducted after the medical condition is diagnosed and other instances where an illness is implied from the gait analysis. This paper uses the traditional description method, as the implication of physical conditions is made through the gait sounds. As gait is a full-body movement, discussion of the feet and ankle joints alone will not suffice. Therefore, the reader must keep in mind the physical movements involving the knee joints, hip joints, pelvis, and torso of the body.

3. Gait biomechanics of the foot and ankle joint

(1) Heel Contact (HC): There is neutral or light dorsiflexion of the talocrural joint, inversion of the subtalar joint, and relative external rotation of the lower limb. There is also supination of the transverse tarsal joint and 30-degree dorsiflexion of the metatarsophalangeal joints. The medial longitudinal arch is curved upwardly due to the windlass action enhancing the stiffness of the feet so that this structure can withstand the shock of HC.

(2) Foot Flat (FF): The talocrural joint is plantarflexed and the subtalar joint is in a neutral position. The transverse tarsal joint returns to a neutral position as the lower limb rotates externally. With the metatarsophalangeal joint in a neutral position, windlass action is released and the medial longitudinal arch assumes a neutral position, lessening the stiffness of the feet.

(3) Mid Stance (MS): The talocrural joint is in a neutral position. While in this single-support phase, the entire body weight rests on the standing foot. According to the vertical component (Z) of a force plate, the instant body weight reaches approximately 85%. As the base of support becomes the area of only one foot, the hip joint is internally rotated so that the center of gravity of the body falls within the standing feet with the eversion of the subtalar joint. At this point, the talocrural joint is also engaged, however, only to a degree of joint play motion. The transverse tarsal joint will want to supinate, and certain functions will come into play to prevent overpronation. The tension of the plantar fascia will work to prevent overextension of the distance between the calcaneus and the proximal phalanges. The medial longitudinal arch is at its lowest. After the MS phase, the talocrural joint is eventually dorsiflexed leading to HO.

(4) Heel Off (HO): When the heel comes off the ground, the talocrural joint starts to move from a dorsiflexed position to a plantarflexed position. As the metatarsophalangeal joints are dorsiflexed, stiffness of the feet increases so that the medial longitudinal arch can curve upwardly due to windlass action. It also has the role to transmit, without waste, the driving force for gait that is created in the lower limb to the ground. There is a relative inner rotation of the lower limb. In the late stage, push off begins

from the head of the metatarsals I to III through the hallux ball eventually pushing off the ground with the hallux. In this stage, the dorsiflexion at the metatarsophalangeal joint is 50 degrees or greater. At the same time, there is HC of the opposite foot, leading to the double-support phase.

(5) Toe Off (TO): The stance phase ends when the toes are completely off the ground and the swing phase begins. During the swing phase, the talocrural joint eventually returns to a neutral position. The dorsiflexion of the metatarsophalangeal joints remains at 30 degrees.

4. Precautions when using sound for gait analysis

Gait sounds arise when the feet make contact with the ground. In the stance phase, this includes HC and FF only. There is no impact sound during HO or TO (Figure 1).

In order to hear the sound, the following precautions should be taken:

(1) Location: A quiet environment with minimal acoustic echo is recommended.

(2) Floor surface: When indoors, a hard floor is recommended. Carpets and other textile floor coverings tend to absorb sound.

(3) Shoes: As bare feet make minimal sound, the use of hard-soled shoes is recommended. Rubber-soled shoes are not suitable, as they do not make much sound.

(4) Clothing: In clinical practice, the patient's whole body movement will also be observed along with gait sounds. Therefore, form-fitting clothing to enable observation of body movement should be worn and loose clothing should be avoided. In order to assist with hearing the friction sounds between the upper extremity and the torso, outerwear made of nylon, such as a windbreaker, should be worn to improve audibility.

(5) Basic conditions to conduct gait analysis: Other than ensuring the specific conditions required for hearing gait sounds basic conditions to conduct regular gait analysis should be met. For example, the following conditions should be

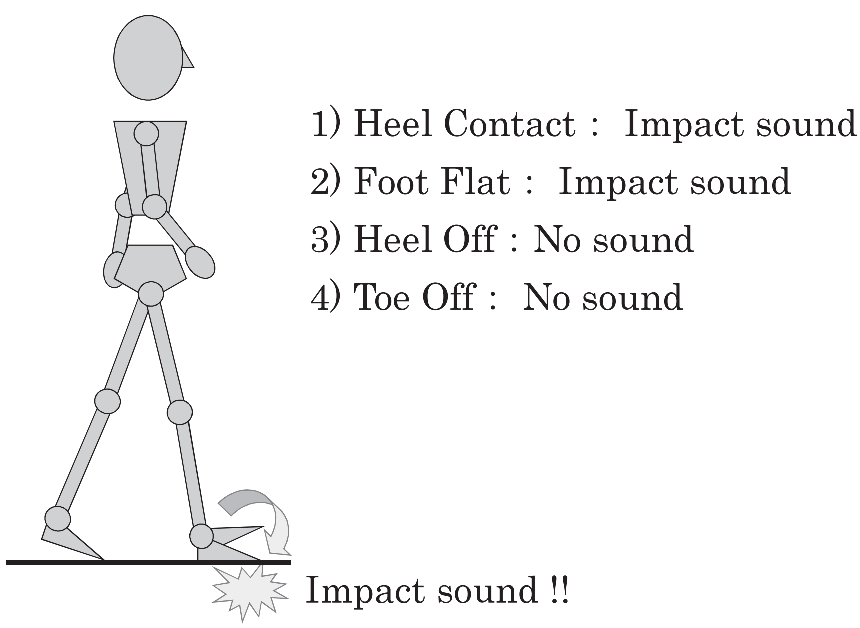

Figure 1. Phases of gait analysis by sound

prepared: i) allocation of an approximately 10 m straight pathway, ii) removal of unnecessary distractions other than the examiner, iii) maintenance of optimal room temperature, humidity, lighting, etc.

5. Gait analysis during HC phase

The difference in impact sounds between the right and left sides during the HC gait phase should be noted. A difference between the right and left suggests that there is an abnormality in either the right or left leg (Figure 2).

(1) Volume: A loud impact sound on one side could indicate "fall-limping" and leg-length discrepancy (the applicable leg is shorter) should be suspected. There is a certain regular pattern between the degree of leg-length discrepancy and the difference in sound volume. Once accustomed, the clinician will be able to easily identify which leg is shorter and by how much (in mm).

(2) Time: A short impact sound could indicate "antalgic gait". Pain is present in the applicable leg. To prevent exacerbating the pain from the load, the patient attempts to shorten the stance time. As time is shortened with worsening pain, it is important to note the right and left time ratio.

(3) Frequency: A high-frequency impact sound could indicate "fall-limping". The reason is, when the applicable leg is shorter, the foot hits the ground from a high position at the end of the swing phase. This can be easily identified when wearing hard-heeled shoes such as men's shoes. While women's high-heeled shoes also have a hard heel, they are not suitable for gait analysis, as the ankle joint is in a plantarflexion position.

(4) Noise: When the impact sound is not clear and it sounds like noise from a dragging heel or sole, it could be caused by an inadequate dorsiflexion of the ankle joint. Muscle weakness of the dorsiflexor muscles of the ankle joint or partial paralysis of its motor nerves should be suspected. A noise is different from an impact sound. As the sound volume is small, close attention should be paid when listening for the sound.

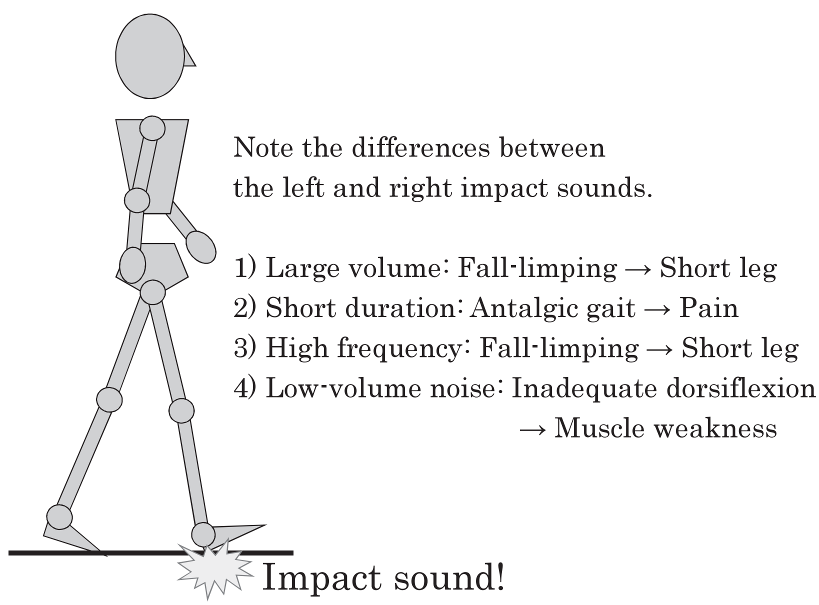

Figure 2. Impact sound of heel contact

6. Gait analysis during FF phase

The difference in impact sounds between the right and left sides during the FF phase of gait should be noted. A difference between the right and left suggests that there is an abnormality in either the right or left leg (Figure 3).

(1) Volume: A larger impact sound on one side signifies a large plantar flexion moment. The cause of increasing plantar flexion moment at this phase could be muscle weakness of the dorsiflexor muscles of the ankle joint or the effect of inertia from the fall-limping. When soft-heeled shoes are worn, the sound volume increases due to foot slapping that occurs from rapid plantarflexion of the ankle joint immediately after HC.

(2) Frequency: A high-frequency sound signifies a strong impact with the floor surface, and a cause identical to that for a large volume should be suspected.

7. Gait analysis through the sound of swinging upper limbs

Simultaneous to the gait cycle, there is swinging movement of the upper limbs. The shoulder joint is extended during HC, returns to the same position as the body during MS and is flexed during TO. The angles of the three joints of the lower limbs (hip, knee and ankle joints) during gait follow a regular pattern, and normal levels are known. However, the normal level of the upper limb swing is much debated, as there are large individual differences. As gait involves alternating movement, a difference between the right and left sides suggests some kind of abnormality.

An example of leg-length discrepancy is shown in Figure 4. During the MS phase of the shorter side, the whole body leans towards the shorter side, the head tilts towards the longer side and the shoulder drops, leading to abduction of the shoulder joint. The hand swings away from the torso of the body, and hence there is no contact

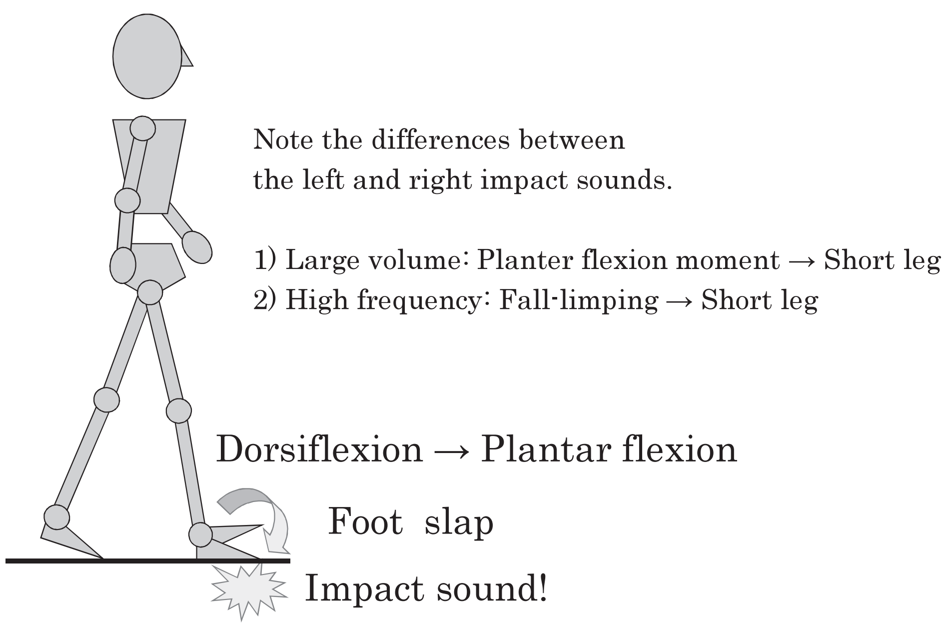

Figure 3. Impact sound of foot flat

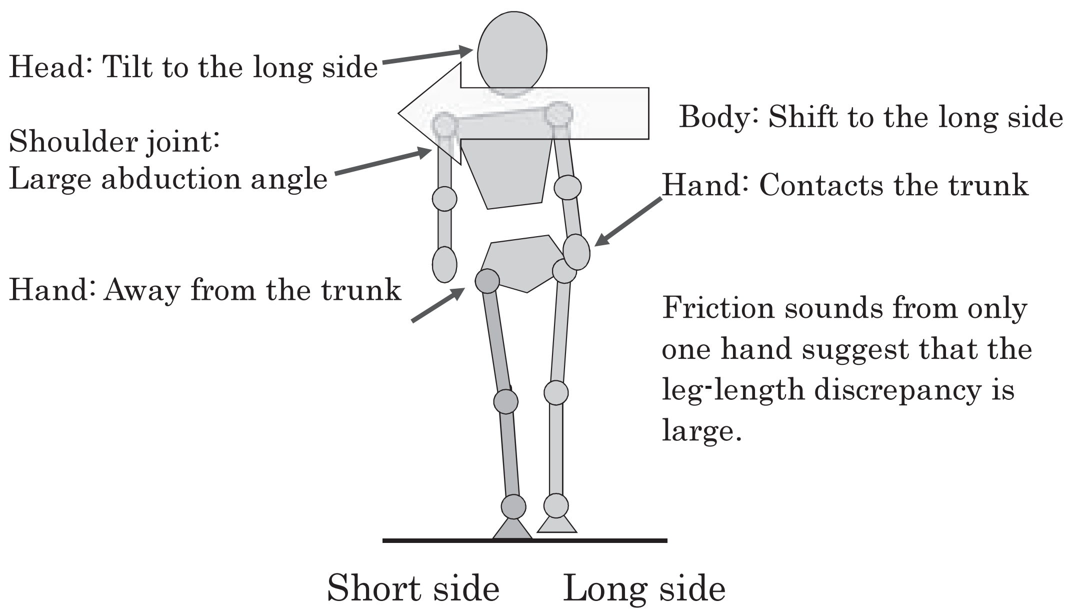

Figure 4. Sound is produced by swinging of the upper limb in contact with the trunk of a patient with leg-length discrepancy

sound. Consequently, the shoulder on the longer side is elevated, leading to adduction of the shoulder joint. As the hand makes contact with the torso of the body as it swings, it makes a friction sound. When the leg-length discrepancy is small, the difference in friction sounds between the right and left sides should be noted carefully. Friction sounds from only one hand suggest that the leg-length discrepancy is large.

8. Summary

Gait analysis through sounds provides an opportunity to detect gait abnormalities during the first observation session. When the clinician detects an abnormality, the movement of the entire body as well as the individual segments and joints should be observed. Detailed analysis with measurement instruments provides numerical data. A wide range of information can be collected by carefully listening for sounds made during gait, such as the presence or absence of sounds, intensity (weak or strong), frequency, and timing. Research to date has yet to quantify these parameters.

Reference

1. Rancho Los Amigos National Rehabilitation Center. Observational Gait Analysis Handbook. Los Amigos Research and Education Institute, Inc., 2001.
2. Perry J. Gait analysis: Normal and pathological function. SLACK, 1992.