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The evolution of clinical gait analysis part III – kinetics and energy assessment

D.H. Sutherland*

Motion Analysis Lab., Children's Hospital, 3020 Children's Way, Mail Stop 5054, San Diego, CA 92123, USA

Abstract

Historically, clinical applications of measurements of force and energy followed electromyography and kinematics in temporal sequence. This sequence is mirrored by the order of topics included in this trilogy on the *Evolution of Clinical Gait Analysis,* with part I [Sutherland DH. The evolution of clinical gait analysis part I: kinesiological EMG. Gait Posture 2001;14:61–70.] devoted to Kinesiological EMG and part II [Sutherland DH. The evolution of clinical gait analysis part II – kinematics. Gait Posture 2002;16(2):159–179.] to Kinematics. This final review in the series will focus on kinetics as it relates to gait applications. Kinematic measurements give the movements of the body segments, which can be compared with normal controls to identify pathological gait patterns, but they do not deal with the forces controlling the movements. As a major goal of scientifically minded clinicians is to understand the biomechanical forces producing movements, the objective measurement of ground reaction forces is essential. The force plate (platform) is now an indispensable tool in a state-of-the-art motion analysis laboratory. Nonetheless, it is not a stand-alone instrument as both kinematic and EMG measurements are needed for maximum clinical implementation and interpretation of force plate measurements. The subject of energy assessment is also given mention, as there is a compelling interest in whether walking has been made easier with intervention. The goals of this manuscript are to provide a historical background, recognize some of the important contributors, and describe the current multiple uses of the force plate in gait analysis. The widespread use of force plates for postural analyses is an important and more recent application of this technology, but this review will be restricted to measurements of gait rather than balance activities.

Finally, this manuscript presents my personal perspective and discusses the developments and contributors that have shaped my thoughts and actions, and which I have found to be particularly noteworthy or intriguing. Just as in parts I and II, emphasis has been placed on the early development. All subtopics and important contributors, in this third and certainly most challenging of the review papers, have not been included. Some may find that my perceptions are incomplete. I accept responsibility for all deficiencies, as none were intended. Letters to selected contributors and their responses reveal how each contributor built on the work of others. The level of cooperation and sharing by these early investigators is extraordinary. Had they wished to withhold information about their own work, clinical gait analysis would have been severely delayed.

Keywords: History; Kinetics; Energy cost; Clinical gait analysis

1. Introduction

The force that the human subject applies to the ground or floor is equally matched by the reaction of the floor or ground. Even primitive man made deductions about the activities of animals or humans from their paw or foot prints. Without any knowledge of Newton's formulae for the effects of gravity and the third law of motion that states, "for every force applied there is an equal and opposite reaction" [3], they understood that bodies have mass (weight), and could deduce much about the identity of animals or humans from the shape, depth, alignment and spacing of the prints they produced.

The search for scientific methods of recording the magnitude of foot/heel contact began in the 19th century. Carlet, of France [4,5], and Ampar, his student, developed and utilized air reservoirs to measure the force applied to the heel and forefoot. Carlet started this work as a student of Marey, at his laboratory in Paris. A significant limitation of

* Tel.: +1 8589665807; fax: +1 8589667494.
E-mail address: dsutherland@chsd.org.

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Fig. 1. Carlet "m" shaped curve produced by subject with normal heel/toe contact utilizing air reservoirs, closely resembles the vertical force curve produced by a modern force plate today.

this method was that it gave only one-dimensional information. Surprisingly, a subject with normal heel/toe contact produced a cursive "m" shaped curve with fair resemblance to the vertical force curve produced by a modern force plate (see Fig. 1). The pressures applied by the body through the foot to the ground are vector forces. The earliest investigators understood this, but they lacked the technology to separate the ground reaction into three dimensions. Fischer [6,7] of Germany deduced three-dimensional ground reaction forces from kinematic studies but did not measure them directly.

With another student, Georges Demeny, Marey went on to develop what would be considered as the first true force plate, which measured the vertical component of the ground reaction using a pneumatic mechanism similar to the one that Carlet had built into the shoe [8]. Jules Amar was a rehabilitation doctor working with amputees during and after the First World War in France. He developed the single component pneumatic force plate of Marey and Demeny to produce the world's first three-component (pneumatic) force plate, which is called the "Trottoire Dynamique" [9]. Wallace Fenn, working in Rochester, was the first to develop a mechanical force plate. This was a one-component device measuring only the fore-aft forces. In an article in which he describes his device, he makes clear the debt he owed to Amar's work [10]. Fenn was fundamentally interested in the consideration of the interchanges of kinetic and potential energy of the segments [11].

As a further development of Carlet's work, Plato Schwartz contributed significantly with his work with a pressure sole, and a device to measure movements of the pelvis. He called the instrument a basograph and used it to demonstrate abnormal pelvic movements associated with specific limps [12]. In 1932, the same authors wrote about "The Pneumographic Method of Recording Gait" refining the original concepts of Marey [13], Carlet [4,5], and Ampar. A quotation from this article by Schwartz deserves mention, "Measurement is essential for the interpretation of normal and abnormal phenomena of the human body. Empiricism, fostered by trial and error, must continue to govern the therapy of abnormal function until measurement in some form improves the treatment of disabilities affecting the back and lower extremities" [14]. Fortunately, we now live in the era he envisioned. Many of his articles followed on foot function, both normal and abnormal using electrobasographic records of gait [15–20]. Dr. Schwartz, an astute clinician–scientist, represents the type of individual so essential as a team member in a clinical gait laboratory.

Elftman was an early pioneer in measuring the forces in more than one plane. With a device he described in a 1934 publication [21], vertical force and the dynamic pressure distribution during a step could be shown, but by Dr. Elftman's own admission, quantification was lacking. In a 1938 publication in *Science*, a device capable of measuring the ground reaction in three planes was illustrated. An upper and a lower platform were suspended with calibrated springs that measured the ground reaction forces and separated them into components [22] (see Fig. 2). In a subsequent article, vertical force and shear forces in the sagittal plane are shown [23] (see Fig. 3). In this article Dr. Elftman discusses potential and kinetic energy, angular moments, and the influence of two-joint muscle action. His work, though hampered by a lack of technical sophistication, was highly creative and scientifically splendid.

It was not until the work of Cunningham and Brown that force plate development took on the features that lend themselves to clinical use [24]. Their plate or platform divided the ground reaction forces into four components. This was achieved with strain gage technology, but the strain gages at that time were quite sensitive to temperature changes. The construction of the platform was complex and constant calibration was necessary. Computer processing of the raw data was not yet available. More technical development would be required before a commercially available plate, suitable for clinical use, would appear. Reduction in the complexity of the platforms, and improvements in the accuracy and reliability of the sensing instruments, came through the efforts of scientists in several locations: San Francisco, California; Boston, Massachusetts; Philadelphia, Pennsylvania; Glasgow, Scotland; Winterthur, Switzerland.

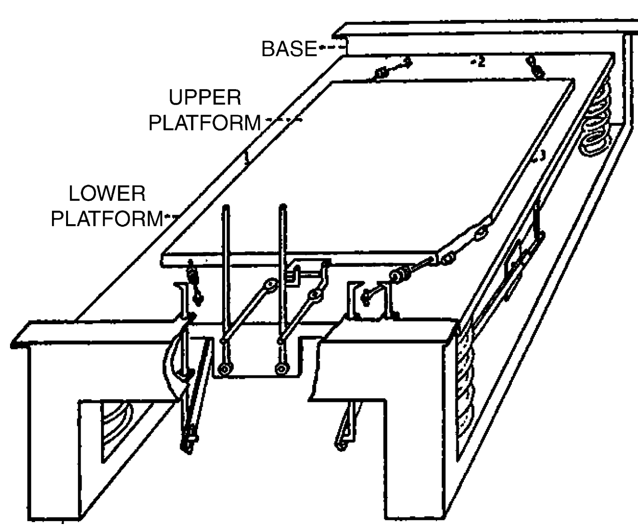

Fig. 2. In 1938, a device capable of measuring the ground reaction in three planes was illustrated.