TECHNIQUES IN GAIT RESEARCH
AND MANAGEMENT OF DATA

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INTRODUCTION

It is natural for humans to have an interest in the way they walk. For one thing it is fundamental to the performance of their everyday activities. For another, it is so complex as to be of interest to a wide variety of disciplines in medicine and science. Finally, both because it is so fundamental and yet so complex, the performance of walking can easily be altered by diseases that affect any one of a number of organ systems, e.g., muscular, skeletal, cardiovascular--and the correction or substitution of this impaired state becomes a matter of upmost practical concern. The need for studying gait, therefore, needs no further defense. However, the manner in which it is studied and the types of information sought, still remain open to debate.

The process of walking involves a complex set of movements primarily of the two lower limb systems, secondarily of the two upper limbs, while balance is maintained in the trunk, which contains most of the load. The control and coordination of these movements involves the neurological system, with force being produced as a complex interaction of the body masses' inertia and weight, active muscle contractions, and passive muscle, tendonous, and ligamentous elements. The resulting movements are limited by the geometry of the joints located between the individual segments and the position and resistance of the external environment (neglecting wind resistance; in everyday situations this becomes the floor or the ground).

For over a century numerous attempts have been made to measure various components of this function objectively, but until recently these have been hampered by the ease, speed, and "naturalness" with which walking could be done. With the advent of modern electronic and computer technology many of the major stumbling blocks have been overcome. It is the purpose of this report to describe the basic principles and some of the most popular methods by which measurements are currently being made and the data so obtained, handled.

KINEMATICS

Modern techniques of gait analysis involve the measurement of both kinetic and kinematic elements. With regard to the kinematic elements a variety of techniques exist to obtain limb segment displacement data. In general the techniques may be divided into three types: (a) visual, (b) optoelectronic, and (c) electronic.

(a) Visual

Perhaps the oldest form still in use, and the most common procedure involves some visual method. (1) Here a camera records the light "emitted" from the various segments of the individual while walking. If the entire cycle is recorded on a single plate it is called a photograph or cyclogram. The latter term refers to the condition when, instead of the reflected light, visualization is made by specific light bulbs located at designated points on the body. This method was first used by the physiologist, Marey (2), and was adopted by many German and American investigators in the early 1900's. By either method, although no data are lost, information regarding the relative displacement of points or limb segments so marked is difficult to discern. For this reason, time must be marked in some way on the photograph. Perhaps one of the easiest ways is to place a rotation shutter in front of the camera. This method is called a chronocyclogram or chronophotograph. A second method is to record the data in a given instance in time on separate photographic plates. Muybridge (3) in the late 1800's first used this method to record the locomotion of horses, by having trip wires in the horses path that triggered a series of cameras. Marey (4) (1885) devised a "photographic gun" which could shoot twelve sequential pictures per second when triggered. Resolution was fairly good as each exposure was 1/720 of a second. This method may be considered the predecessor of cinephotography. Marey actually developed his gun prior to his use of chronophotograph, but abandoned it because of the limited number of pictures he could take within any given time period. Though by the 1920's cinephotography had improved, it did not offer a frequency range considered fast enough for accurately depicting human movements (Bernstein, 51). Although rapidly rotating shutters used in cyclograms could achieve this frequency, at the desired speeds the position of individual points was difficult to decipher. For this reason Bernstein combined a rapidly rotating shutter with a slowly moving film to distinguish points in a trajectory at frequencies of up to six hundred per second. This technique (Kymocyclography) is rarely, if ever, used today and in general has been replaced by cinephotography (6). Cinephotography in its present state has the advantage of using ambiant light, does not require the subject to wear or use any specific equipment, and can "shoot" a sequential series of pictures several hundred to a thousand times per second. It also offers good resolution, the ability to see an entire limb segment or segments, and provides a wide and adjustable range of field depths. It has the disadvantage of a film record, which is expensive and not reusable, and only able to be viewed after a time period for developing.

To overcome some of these disadvantages the subject can be photographed on videotape using a TV scanner. Visualization and recording are made from a phosphoric screen where the image is illuminated every 1/60th of a second (520 horizontal lines are sequentially scanned). The disadvantage of this method at least until now, has been its resolution. The lines "float", not maintaining a fixed position with regard to a reference, and the number of lines are "relatively" few. These disadvantages promise to be corrected in the near future with further advances in TV technology.

In all of the methods so far described, the desired temporal recording of events has been made by alterations in the receiving equipment. Sequential "pictures" can also be obtained if interrupted light is used.

The simplest method would be by flashing lights, i.e., a strobe. In its current technology it offers the disadvantage of having to be produced in a darkened room and can interfere with the subject's ability to walk--producing "atypical" gait. This is especially true if the subject being studied has gait abnormalities stemming from neurological disorders, but can be circumvented if the interrupted light source is directly on the subject. Such a method was originally used by Braune and Fisher (1895-1904) (7) with flashing tubes controlled by a spark inductor with frequencies up to approximately 100 per second. This method may be considered the precursor of the modern "SELspot" (Selective Spot Recognition System) (1,8), which has frequencies obtainable from fifteen "mini-LCV" (small light emitting diodes) of 322 times per second. In its current form it requires a large cable to follow the patient or requires the patient to carry a 400-500 gram transmitter pack. The latter method, although acceptable for adults, is not acceptable for small children. Additional details of this method are described below.

The displacement of an object in space, i.e. changes in all three spatial coordinates of the object, requires observation from no fewer than two points of view. All of the above methods afford this option and have been incorporated into the system ever since the first measurements were made. Braune and Fisher utilized four cameras, while Bernstein used fewer cameras but reflecting mirror placed more than one view on a recorded image. If additional "cameras" are employed some means of synchronizing the images obtained from each must also be incorporated. Depending on the type of "camera" and the frequency with which the movements are recorded, various devices have been added either as part of the recorded data or incorporated into the recording equipment. The methods and accuracy of each are beyond the scope of this survey. Suffice to say that this is not a significant limitation to the accuracy of the techniques developed.

Except for the SELspot system, in all the visual methods herein presented, the data recorded is not in a form suitable for kinematic analysis. Further processing (analytic photogrammetry) must be performed.

Perhaps the greatest progress in the study of locomotion in the past ten years has been in this area. The advent of modern electronic and computer technology has made it possible to perform this task more rapidly than was previously done by hand. With new techniques, processing has been translated from a chore requiring days, to one performed in hours or minutes. It promises, in the near future, processing within seconds. The field of analytic photogrammetry for industrial and military purposes has developed elaborate techniques with almost unlimited capabilities. Although these techniques are fully automatic and can easily scan cine film in rapid order, they are not in use for the evaluation of human locomotion, primarily because they are prohibitively expensive. Other techniques designed specifically for and by researchers working in human locomotion, have been developed for this reason. Perhaps the most popular method currently being used is some form of a semiautomatic system using a sonic digitizer. This consists of a series of small sonic receivers organized in linear arrangement along two mutually perpendicular arms of the frame. A "sound sensitive gridspace" is thus formed into which is placed the "pictures" to be "measured." These pictures can be a cyclogram or graph, a cine photogram, or SELspot data. The unit operator then specified the location of the point whose cordinates are to be recorded by touching the spot on the projected or actual film image with a sound emitting cursor. Resolution is thus very accurate, as the limitations to the system are the photographic lens used to photograph the image originally, the size of the original photograph as it is being projected on the gridspace, and the size of the individual gridsquares. To give an example, the current method used at the Gait Analysis Laboratory at Boston Children's Hospital Medical Center, utilizes 3-16 mm Photosonic cameras*, having 12.5mm and 25mm lens, located eight and ten meters from the subject, a Vanguard Motion Analyzer** as a projector unit (images of about 15x15 inches), and a GRAF-PEN Sonic Digitizer*** consisting of a frame which establishes a grid over an area 2500x2500. With such a system, resolution of approximately 1mm can be obtained. As they are currently being used, most digitizers are under computer control and various schemes of data recording incorporate both hardware and software components. The type of system developed depends on the needs of the investigator and the degree of human-machine interaction desired.

(b) Optoelectronic Devices

The incorporation of electronic-computer processing devices with visual systems can be considered, in the strict sense of the word, optoelectronic methods. This method in one form or another is the most widely used system for obtaining and processing displacement data today. Its advantages are the merits of each system component and as such depend on an individual laboratory's needs. A system can be put together in a variety of ways. It has the disadvantage, however, of being only semiautomatic; it still requires man hours to obtain data and does not have the ability to acquire these data in "real-time." An example of such a system in the author's laboratory, where this process requires one half to one day of film developing and an additional one hour to computerize one gait cycle (which consists of recording twenty anatomical areas from three filmed projected images). This is the most rapid time period that this system is capable of reaching at the present time (9).

In order to eliminate the man-hours still spent in digitizing and to obtain real-time data, "truer" optoelectronic systems have been developed (10, 11). In one type a videotape is replayed onto a tungsten phosphorant grid screen. Only large reflective markers (semicircular ping pong balls) are sufficiently bright when so projected to illuminate the screen. The screen is transformed into matrix, stored in the computer memory. In this matrix the bright markers have the value of one, while the dark ones have the value of zero. The screen can be

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* Photo-Sonics, Inc., Burbank, Ca.

** Vanguard Instrument Corp., Melville, New York

*** Science Accessories Corp., Southport, CT.

scanned sequentially from left to right, top to bottom, and sufficient time to record the coordinates of the illuminated points before the subsequent data-points are produced. Each scan then becomes a frame. Its disadvantages include difficult calibration, low resolution, large software (memory) programs and "limited" sampling frequencies. Another type of optoelectronic device utilizes infrared light emitting diodes, placed on the subject and viewed by receiving cameras whose photographic plate is a voltage grid. Each light source is pulsed in rapid sequential fashion so that the grid sees only one spot at a time. Outputs in two directions are analog voltages. For automatic processing appropriate rapid computer software and analog to digital signal converters are needed to identify each spot as a landmark and assign a fixed number of spots to a frame. With appropriate standardization, the true (parallex free) rectalinear coordinates of each spot can be obtained and the same spot found on several cameras can be combined to produce its true position in space. The SELspot system*, incorporating all of these features, can take up to fifteen spots 322 times per second, but in its current model has several disadvantages. Resolution is two to three times less than that of previously mentioned optical methods. Although the voltage grid has a resolution of 1000x1000, this is not well utilized as the limiting factor appears to be in the LED's and ten bit words produced in the analogue to digital conversion. Field range and paralex correction appear limited by camera lens. In addition the LED's appear to produce extraneous points from reflections created by them on the floor. This makes it difficult to use the LED's on positions lower in height than the knee. Similar in principle but somewhat different in detail, is CODA (Cartesion Opto-electronic Programmic Anthropometer). Little information is currently available on this system (12).

Rather than have light emitted from the patient, an alternative approach is to have the light produced elsewhere and allow sensors on the patient to pick up the light. Knowing the angle of incidence, the sensors position in space could be determined. This principle is currently incorporated in the POLGON (Polarized Light Goniometer)**(12, 13) A projector emits a diverging beam of polarized light. This is directed toward sensors located on the walking subject. "Each sensor consists of a pair of photocells mounted behind polarizing gilters," the "plane of polarization within the sensors are set at right angles to each other." A polarizing filter placed in front of the projected light is rotated at a rate of 8000 r.p.m., making the sampling rate 133 H_z. "The time phase relationship between the signal from the reference source and limb mounted sensors is used to provide concurrent outputs of voltage analogs of the angular orientation of each of the sensors." Resolution is better than .2 degrees. The minimum distance from walkway to projector is four meters, and the maximum is ten meters. The principal drawback

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* Selective Electronic Co., S-43121, Molndal, Sweden

** Crane Electronics STD, Warwickshire CV93PJ, U.K.

appears to be the system's ability to assess only the angular orientation of a limb segment in space, and the limited number of sensors it can process.

(c) Electronic Devices

In an effort to produce real-time low cost data, other electronic devices have been produced. In principle sound waves can be used in the same manner as light waves, but to-date sound waves have had only a limited application in the measurement of limb displacements. It has been used to a limited extent to measure angular displacements, as has the polarized light goniometer. In single joint analysis, i.e., measuring the relative displacement between the adjacent limbs, perhaps the most popular method currently employed uses electric goniometers. Such devices will be dealt with in greater detail in another section of this Workshop (by an author more familiar with it than the present author). Suffice to say, like all the electronic devices it offers many advantages but has the disadvantages of being encumbering to the patient, subject to considerable vibrational and cross-talk errors, and in its present state does not provide spatial positioning information.

CRITERIA FOR SELECTION OF DISPLACEMENT DATA ACQUISITION SYSTEMS

Although no one system is ideal, it is obvious from the above descriptions that a variety of good data acquisition systems are presently available to obtain desired displacement information during walking. With any system, trade-offs between advantages and disadvantages must be made, but with few exceptions, all currently used systems provide the opportunity to study gait with greater ease than hitherto. The criteria for the selection of a system will depend on the type of information desired, the subject population to be examined, and the overall purposes for which the examination is performed.

If multisegment analysis is desired one must be concerned with a large amount of input information while maintaining appropriate identification of each area, and determining each segment's relationship in space. If the entire body is to be examined, no fewer than fifteen body segments must in some way be monitored. Hands and assistive devices crossing the paths of motion of the lower limbs, or one side of the body crossing in front of the other side, must in some way be dealt with. If single joint analysis is desired, the problems created are much fewer in magnitude and easier to solve. Table I lists some of the methods presently employed in each situation. The subject population under study will further limit the choices available. For subjects with pathological disorders, the type of disorder or assistive device necessary for walking, become important factors to consider. Visual disturbances can distort the gait pattern if good lighting is not provided. Neuromuscular or skeletal-joint disorders involving the use of braces or orthoses, can prevent the donning of certain types of apparel. The examination of children mandates the use of comfortable surroundings, minimal time in patient preparation, and minimal equipment encumbering the body. All these factors become of greater importance of the measurement of other parameters, such as muscle function (with EMG), is also to be performed. Finally objective assessment of the gait characteristics of the subjects examined in a clinical research setting is far different than the assessment made to assist the clinican in his everyday work i.e., as a clinical nonresearch tool. In the former case, patient loads are apt to be smaller, greater accuracy in the data is apt to be demanded, and the absolute magnitude of the parameters measured is likely required. In the latter case, real-time information, speed of patient preparation and handling, reliability and longevity of equipment, reproducibility of selected landmarks over longer time periods, and relative values of the parameters selected (rather than the absolute values) are more significant criteria in technique selection.

Regardless of which technique is chosen, a certain degree of inherent error will always be present. The only aspects of the limb segments that are rigid masses are the bones; yet all present day techniques utilize various landmarks located on the external covering of the segment, the skin. As such, noise superimposed on the true information is produced in the actual measurement. This noise is due to movements created in the skin by vibrations transmitted from deeper inertial accelerations of the tissue mass, by vibrations transmitted along its surface when the foot impacts the floor and by movements of the underlying tendons and contracting muscles loosely attached to it on its inner surface. The smaller the soft tissue mass below the skin, and the slower the speed of gait, the less the noise. It is for this reason that most techniques utilize landmarks over joint surfaces and data collected from patients who walk slowly may be better than data collected from those who walk at normal speeds.

A number of techniques have become available to filter out the true signal from the noise (14, 15, 16). These are based on the principle that such signals occur with speeds slower than that produced by noise. The utilization of these techniques is dependent upon the recording of the data at a speed faster than either type of movement. For gait, researchers examining the question feel that sampling frequencies of fifty times per second, or greater, are more than adequate (14, 17, 19). The specific technique employed to filter the true signal will depend on the information desired and from which area of the body such information is obtained. If quantitative information, such as velocities and accelerations, is to be derived from displacement data, some smoothing technique is needed (18, 19). The need to perform such a procedure will also then influence the basic measuring methodology.

KINETICS

In addition to determining the kinematics of the subject while walking, valuable information can be gained from examining the kinetics of the system as well. To do this for each body segment is unfortunately a more difficult task than determining their respective movements. The techniques utilized in assessing the kinetics of the system can be divided into those that can be performed directly (measurable quantities) and those that can be indirectly determined by calculation.

Neglecting wind resistance, total external force applied to the body is manifested in the foot-floor interaction. This can be measured with the use of a force plate set in the floor, or perhaps even placed inside a shoe. The former method was suggested as a useful device as early as 1930 (2) and theoretically calculated by Braune and Fisher as early as the turn of the century. Force plates currently being used can determine the three mutual orthogonal components of the foot-floor reaction force vector (vertical fore-aft, medial-lateral) the torque in the horizontal plane as well as the center of pressure of the foot in any instant. If force plates are transparent, the contacting area of the foot with the floor can be assessed; hence pressure distribution at any given instant can be determined. Two plates currently available have this potential.* As in the motion-analyzer systems, some inherent error is present in this apparatus as well. Pure vertical load applied to the plate will register forces in the horizontal plane with a magnitude of 1-3 percent, depending on the type of plate used. This crosstalk between mutually perpendicular directions seems small in magnitude, but it must be noted that the fore-aft forces during gait maximally reach approximately 20 percent of the vertical load but medial-lateral forces are only about 5 percent of the vertical load. A second error arises from motion of the plate when struck. The plate will ring (resonance) like a tuning fork, and hence creates signals of forces which for all practical purposes must be considered noise. This is present at heelstrike and for about the first 10 percent of the cycle thereafter. Originally designed plates had a resonant frequency of 35 H_z which was close to that of the body's motions: however present day plates using piezoelectric transducers and more modern strain gauges have resonant frequencies at 100-200 H_z, greatly reducing their contribution to the noise signal. A new strain guage plate (recently acquired in our laboratory**) has resonant frequencies of close to 500 H_z; the only high frequency impulses created by the body present in walking is therefore found to be a one to two m.sec. impulse occurring at heelstrike. Frequencies of up to 100 H_z are present in the recordings of the cycle. For practical purposes, therefore, this implies that hardware or software low pass filters with a cutoff frequency of 125 H_z, and with sampling frequencies of the signal of 500 m.sec., may be used to eliminate noise. This procedure is currently being used in most gait laboratories. With such sampling procedures high demands are placed on data storage over short periods of time, since five to seven channels must be sampled at this rate.

Though force plates in shoes hold interesting promise, to date no practical design that is reasonably noise free, and has minimal crosstalk, has been developed. Two major theoretical limitations to further development using shoes, would be the necessity for each laboratory to have a number of these present in different sizes, and the necessity of having

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* Kistler Instruments Ag, CH-8408, Winterthur, Switzerland

** Biomechanical Research Systems, 1751 Santa Cruz Ave., Santa Clara, CA.

a backup system to determine the foot's orientation in space and position relative to the floor.

The forces acting on each limb segment can directly be measured by the use of accelerometers, if mass, mass center and inertial properties are known. A number of investigators have recently been exploring this technique. Small accelerometer packages of three, six or nine units have been used to insure avoidance of directionality problems (21, 22, 23, 24, 25). Although small in size they would need to be fixed to the skin where a minimal amount of underlying soft tissue is present, in order to avoid considerable noise problems. Its position in space must be independently determined if it is to be used to calculate velocities and displacements by integration. To date accelerometers have not found wide popularity in areas of the body other than the tibia, sacrum, head and shoulders (26, 27, 28).

Forces about joints as well as energy expenditures of various limb segments can be calculated either from accelerometers and/or from a combination of data derived from motion displacement and force plate data (29, 30, 31, 32, 33, 34, 35, 35, 37, 38). The determination of this parameter, for one or many joints, requires such extensive calculations that it is only feasible with computers.

Ideally one would like to perform intra-vital measurements of forces occurring in the muscle, tendons, ligaments, and bone. To date the closest that modern techniques have come to this goal, have been strain guage recordings of a femoral prosthetic replacement (39), nail-plate insertion into the proximal femor for internal fixation of a fracture (40), Harrington Rod implantation for internal fixation during scoliosis correction and spinal fusion (41), and direct recordings of strain guages placed on the human tibia. In only the first instant and the last two have recordings been made during gait. With the common treatment modality of total joint replacement as a standard part of the orthopaedic armamentarium, it is possible to obtain a greater knowledge of the forces present around certain joints during gait with the use of small electronic packages such as pressure recorders and telemetry devices. To date, however, none have been implanted (44).

Since muscles are the force actuators of the body, the forces that they create during walking are of prime interest to investigators in this field. This measurement has totally alluded any reasonable approach partly because of the anatomical and physiological properties of the system. To date the only property of this organ system that can be ascertained is the depolarization of the sarcomere membrane of individual motor units. (EMG of motor action potentials). To examine the voltage changes occurring during this physiological phenomenon, electromyography is used. For a review of this subject, the reader is referred to the excellent book by Basmajian (45). However, in the study of gait, two basic techniques have been standardly used and for the sake of completeness should be mentioned here.

The first is the use of extremely fine wire, intramuscular electrodes (46). The pair of electrodes consists of 106 mm. diameter wires, insulated with a polyurethane coating over the entire length. The wires are threaded through an injection cannula of 27 guage, the loop used to insert it is cut, the wire ends are deinsulated over the last two mm. of their length and are then bent around the end of the cannula. After the wires and cannula are sterilized they are inserted into the desired muscle and the cannula withdrawn (47). The second technique employs the use of a pair of electrodes, approximately one quarter of an inch in diameter, placed on the skin (surface electrodes) over the bellies of the desired muscle groups. Wire electrodes because of their small exposed ends and direct contact with the muscle are able to register voltage changes of only five or six motor units within a given muscle. The advantage of this is the assurance of obtaining only the signal from a single muscle and offering the ability to easily judge the intensity of the muscle contraction. These advantages are only in the eyes of the beholder, as the same factors are considered by others to be disadvantages. Since the intensity of muscle contraction involves an increase in the number of motor units acting as well as an increase in the firing rate of each individual unit, a more representative measurement could be obtained from surface EMG's. This factor may be even more significant if certain diseases utilize one type of contractility behavior over another, or have created non-uniformity in the action of the motor units. Surface EMG's offer the additional advantage of being a painless procedure. However, they have the disadvantage of not being able to evaluate deep seated muscles and the unfortunate disadvantage of, at times, picking up activity from adjacent, unwanted muscles. Because the power spectrum of surface EMG's has been found to be lower than that of needle EMG's, it offers lower digital sampling frequencies, if so desired, which are on the order of 500-1000 H_z rather than the 1000-2000 H_z for needle EMG's. In both cases some form of high-pass filtering in the hardware or software is necessary, as noise created by motion artifacts and electrical signals in the room environment where the gait studies are held are commonly found. No uniform standard for the cutoff frequency has been established, but has been usually considered to be between 20-60 H_z.

Any assessment of the EMG signal beyond an indication of the phasic on-off activity of the muscle is difficult to do. To obtain some idea of the intensity of the contraction, further processing of the signal needs to be performed. A variety of techniques and parameters have been used (45); all can be performed via hardware apparatus or via computer software processing. Processing the data in one form or another prior to storage is preferred. However, this limits what can be done and prevents any further processing in the future. It must be emphasized that although modern electronics and data processing systems permit elaborate means of processing EMG signals, such methods only provide a manner of determining the <u>electrical</u> intensity of the contraction. The exact relationship between this and the intensity of the force observed, even in normal muscle, is not at all clear and is even less so when pathological disorders affect these muscles. This appears to be true in both the magnitude and phasic timing of the two parameters.

OTHER TECHNIQUES OF DATA ACQUISITION

A review of modern data acquisition systems would not be complete without mentioning the devices that have been produced to measure a limited but very significant number of parameters of gait. Various laboratories have developed electronic hardware to rapidly and easily determine gait velocity. In addition the timing of the individual phases of the gait cycle has been found to be a valuable clinical parameter and can easily be ascertained with new devices measuring merely the foot-floor contacting times (48).

DATA STORAGE, PROCESSING AND DISPLAY

Concomitant with the explosion in the development of modern techniques of gait analysis, electron technology and computer science have provided the means by which such information can more rapidly and more easily be stored, processed and displayed. The availability of such devices in the area of gait analysis has perhaps been the major reason why interest in this field of applied research and clinical assessment has expanded so rapidly in the last decade. The expanding capability of relatively low cost, mini-computers has made hitherto arduous procedures of data processing become a thing of the past. In earlier research, computers were merely used as in-stage processors, reserved for extremely detailed and complex calculations. Computers are now being used in every step of gait analysis, from data acquisition, to storage, to processing, to displaying. Not only have they significantly reduced the time required to obtain information from gait analysis, but in certain cases without them the techniques developed would not be possible. The speed in handling large volumes of information, from many inputs and outputs, allows easy integration of the many kinetic and kinematic parameters of gait. Table 2 lists the various ways in which information can presently be stored and displayed. Which system is to be used is dependent upon each laboratory's priority of: (a) amount of information to be stored or displayed per patient, (b) need for rapid access to such information, and (c) cost effectiveness per patient. A great deal of effort has been expended in establishing computer-based systems and sub-systems. With the use of such devices and methods, the variety of pathological disorders examined can be expanded, as more patients can be examined per day. EMG, force plate, and motion data "raw" form can be rapidly displayed in Marey's simplistic, but very informative diagrams, but containing more information that Marey ever thought possible. Such diagrams were Elftman's and Bernstein's qualitative representation of the dynamic state of walking. Using such diagram communication between various medical and scientific disciplines is assured. Calculations of velocities accelerations, forces, energies and power are not only possible, within short periods of times, but can be combined with other parameters of gait, such as muscle activity, to provide a greater understanding of the gait process and answer indepth questions (34, 49). In short, the modern techniques of gait analysis and and the currently employed methods of data handling have altered the emphasis of work in this field, from that of developing techniques of acquiring data to determining the ways in which it can assist the researcher and clinician in performing their job.

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TABLE I

Single Joint Analyses

- Polarized Light Goniometers
- Ultrasonic "Goniometers"
- Electrogoniometers

MultiSegment Analysis

- Stroboscopic Photography
    - single plate
    - low speed film
- Cinematography
    - isolated
    - projected image measurement
- Scanning Chronocyclograph
- TV Picture Analysis
- "Selspot"

Simon cont.

TABLE II

Storage Systems

- Analog Type
  - 7, 14, 28 Tracks
  - FM or AM
- Computer Discs
  - Plain
  - Floppy
  - Multiplatter
- Digital Tape
  - "DEC" Tape
  - Cassette Tape
- Memory
  - Semiconductor
  - Core
  - CCD (Charge Couple Device)
  - Bubble

Output Devices

- Storage Oscilloscope
- X-Y Plotter
- Graphics Terminal
- Line Printer
  - Mechanical
  - Electrostatic
- Video Monitors