SECTION I
INTRODUCTION

1. OVERVIEW

The National Center for Medical Rehabilitation Research (NCMRR) was established within the National Institutes of Health (NIH) by legislation (P.L. 101-613) passed in 1990. The Center is a component of the National Institute of Child Health and Human Development (NICHD). The mission of NCMRR is to foster development of scientific knowledge needed to enhance the health, productivity, independence, and quality of life of people with physical disabilities. The primary goal of the Center is to bring the health related problems of people with disabilities to the attention of America's best scientists in order to capitalize upon the myriad advances occurring in the biological, behavioral, and engineering sciences. This is accomplished in part, by supporting research on enhancing the functioning of people with disabilities in daily life. Periodically the Center also sponsors workshops which allow experts in a field to gather and focus on a topic of interest. This document contains a detailed description of the design, execution, results and interpretation of the workshop "Gait Analysis in Rehabilitation Medicine."

1.1 Purpose

The primary purpose of the workshop, described within this document, was to develop and prioritize a set of recommendations that pertain to the future role of gait analysis in enhancing the function of people with disabilities due to functional limitations of the locomotion system. Although the workshop was entitled "Gait Analysis in Rehabilitation Medicine," the range of topics which gait encompasses is much broader than the classical definition of bi or quadri pedal motion might imply. Gait clinics and laboratories include analysis of many forms of human locomotion which often include the use of assistive devices such as crutches, canes, prosthetics, and wheelchairs. The types of activities studied in motion analysis centers had expanded to include stair climbing, chair rising, and many other activities of daily living. This expansion is, in part, due to the realization of increasing interest in providing greater clinical service to rehabilitation professionals. Gait analysis shows promise to be of substantial assistance to rehabilitation professionals as gait laboratories gain greater experience in this arena. It is hoped that the information gained from this workshop will be helpful in guiding the collective efforts of experts whose professional ambitions include enhancing the lives of people with disabilities.

1.2 Background

The subject of gait has been of interest to humans for several centuries. Early scientists were satisfied with describing the gait of humans and animals to derive a sense of form and beauty. The first technical analysis of gait has been credited to Muybridge during the late 1800's. Muybridge was tasked with answering the question of whether all four feet of Leland Stanford's horse "Occident" were ever off the ground simultaneously during a trot. Muybridge tackled the problem by developing a special high speed multi-frame still camera. Muybridge's photographs were astonishing, and proved that Occident's feet did

indeed leave the ground during a trot. Gait analysis has come far since these humble beginnings.

Involvement in the coordination of gait analysis research activities by the Federal Government has been sporadic. The first effort was a task force Standardization of Gait Analysis Parameters and Data Reduction Techniques formed by the Committee on Prosthetics Research and Development of Life Sciences, Division of Medical Sciences of the National Research Council for the National Academy of Science. This task force had six meetings: Chicago, January, 1970; Cleveland, February, 1970; Philadelphia, March, 1970; Iowa City, December, 1970; Berkeley, March, 1971; Downey, CA, February, 1973. These meetings mainly considered standards issues such as defining flexion-extension, identifying terms such as heel strike or foot contact, and trying to define standards for filtering electromyographic (EMG) data. There was also considerable discussion on means of sharing data and how to encourage the expansion of the technology for clinical use and research purposes.

The next effort was a Gait Research Workshop held at Children's Hospital Health Center, San Diego, California in the month of March, 1977. The meeting was sponsored by the Applied Physiology and Orthopedics Study Section of the NIH. The goal of this meeting was to give direction to increasing requests to the NIH for funds to start gait laboratories. Another goal of this meeting was to define the state-of-the-technology and help give direction for its development. Unfortunately, a clearly defined set of conclusions or recommendations was not developed from this meeting. There did seem to be a consensus in the final discussion that: 1) Federal research should focus more on testing and developing applications as opposed to new technology. 2) That work using quadruped animals is to be continued, and 3) funding should be directed at established laboratories as opposed to funding the establishment of new laboratories. There also was a lot of interest in fostering interdisciplinary and multiple center cooperation, which led to on going discussion into issues of standardization. Since this meeting in 1977, there has been no formal organized effort from NIH with respect to gait analysis.

Technological advancements during the past decade have brought dramatic changes to the gait analysis community. Film and camera have been replaced by charge coupled devices and computers, but the same basic concepts remain unchanged. Equipment for capturing kinematic data has become much faster, and is "real-time" for some systems. Three-dimensional analysis has become the standard for both research and clinical gait analysis. Gait analysis also has moved on to take a more integrated approach. Many tools have been developed to aid in the search for a better understanding of function and to improve the clinical relevance of gait analysis. Force platforms are the norm for nearly all laboratories. The combination of kinematic and kinetic analysis provides a more comprehensive view of the mechanics of motion. Electromyography is also routinely used with three-dimensional kinematic and kinetic analysis. The combination of these three data collection tools in parallel with computer modeling have provided substantial insight into the origins and control of human movement. This is, perhaps, the future of gait analysis.

Tremendous progress has been seen over the last 20 years since the National Institutes of Health organized a "Gait Conference." Although there is wide spread use of gait analysis for both research and clinical diagnostic purposes, there is no clear understanding among many government and non-government agencies of the state-of-the-art of the technology, and future directions for research. The participants in this meeting worked to identify a set of prioritized recommendations for the future development of human movement analysis within a rehabilitation context.

This meeting had its origin when Dr. Freeman Miller discussed the use and benefit of diagnostic clinical gait analysis at the fall 1994 meeting of the Advisory Committee of the National Center for Medical Rehabilitation Research of the National Center for Child Health and Human Development. Dr. Edmund Chao, a board member at the time, was a strong advocate for the concept. A small planning meeting was formed by Dr. Louis A. Quatrano of the NCMRR to organize the specifics of the workshop. Members of the planning committee were: Edmund Y. S. Chao, Ph.D. (Chair), Johns Hopkins University, Baltimore MD; Rory A. Cooper, Ph.D., University of Pittsburgh, Pittsburgh, PA; William J. Heetderks, M.D., The National Institute of Neurological Disorders and Stroke, NIH, Bethesda, MD; John H. Mather, M.D., Social Security Administration, Baltimore, MD; Daniel McDonald, Ph.D., Division of Research Grants, NIH, Bethesda, MD; Freeman Miller, M.D., A. I. duPont Institute, Wilmington, DE; Jo Pelham, Division of Research Grants, NIH, Bethesda, MD; Louis A. Quatrano, Ph.D., NCMRR, NIH, Bethesda, MD; Steven J. Stanhope, Ph.D., Rehabilitation Medicine Department, NIH, Bethesda, MD; Ronald T. Triolo, Cleveland VA Medical Center, Cleveland, OH.

The execution of this workshop was preceded by a year long planning process. To develop substantial documentation and capture participant perspectives, an innovative structure for the meeting was developed by Dr. Stanhope. The unique features of the meeting were to: assign workshop participants to one of three breakout work groups charged with the task of developing a set of written recommendations under a broad working group topic, use a team approach augmented with facilitation to enhance recommendation development, have all participants review and prioritize all of the recommendations, and accomplish these tasks within a two and one-half day workshop.

Development of this document occurred during a three month post-workshop period of time. This involved the concerted efforts of the conference coordinators and the six topic co-chairs. In addition, the six experts who presented key concepts to workshop participants prior to the recommendation development sessions clearly expended considerable personal resources during the preparation of their outstanding lectures. Conference participants worked diligently on their personal statements and exhibited an extraordinary level of enthusiasm, productivity, and congeniality under what can best be described as extreme circumstances. The unselfish commitment that each and every one of these individuals displayed towards the preparation, execution and documentation of this workshop is here by acknowledged and consummated by the very existence of this extensive document.

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1.6 Participant Personal Statements

1.6.1 Introduction

Workshop participants were requested to submit personal statements pertaining to the role of gait analysis in rehabilitation medicine prior to the meeting. These statements were provided to each participant in the form of a pre-workshop mailing for the purpose of facilitating discussion during the breakout sessions. Following the workshop, participants were provided the opportunity of updating their statements. In doing so, Drs. Perry and Sutherland were kind enough to contrast this workshop with the previous (March, 1977) NIH sponsored event. We wish to honor Drs. Perry and Sutherland's efforts by placing their comments in the body of this section. The contents of all remaining personal statements in alphabetical order may be found in Appendix A. Readers are strongly encouraged to review these materials. They are profound statements, developed with great care and thought by many of the current and future leaders of this field.

Major Issues in Gait Analysis in Rehabilitation Medicine

Jacqueline Perry, M.D.

The supportive theme of the 1996 workshop on Gait Analysis in Rehabilitation Medicine is welcome reassurance of the progress that has been made in this field of research and development. Today, the workshop objectives are to enhance the effectiveness of gait analysis as a clinical tool. Twenty years ago (March, 1977) at the first NIH Gait Workshop, six leading investigators of gait analysis were challenged to defend the scientific and clinical worth of such endeavors. Sponsored by the Applied Physiology and Orthopedic study section division of research grants, the purpose of the first workshop was to explore the logic of continued support for gait analysis research. A basic concern was the high space and instrumentation costs of gait analysis. The study section questioned the underlying theoretical concepts, the potential contributions to basic and clinical research, and the value of objective gait analysis as a clinical procedure. As one of the defending investigators, I found the environment cordial yet tense. In our effort to generate support for gait analysis our presentations focused on the scientific and clinical accomplishments. None of us dwelt on the laborious effort required to process and interpret the data. This led to a conclusion by the study group that gait analysis instrumentation need no further development unless it related to a new investigative direction. Overlooked was the observation that there still were no "clinically-useful diagnostic tools" to allow patient testing outside of a heavily financed research laboratory. This last comment justifies the focus on technical development which has occurred during the subsequent twenty years. In response to such development, there now are many clinically oriented gait laboratories. This is particularly true for children's hospitals where the challenge to provide optimum surgical enhancement of the child with cerebral palsy is strong. The study group also concluded that good research questions were being investigated but more collaboration among scientists of different disciplines was needed to facilitate progress.

The proposed topics for the current, 1996 workshop are well designed to support the basic objective of advancing the effectiveness of gait analysis in rehabilitation medicine. Justification of instrumented gait analysis depends on three situations. First is the clinicians' appreciation for the limitations of observational analysis. Secondly, is the availability of a reliable laboratory (instrumented) system in the clinicians' community. Thirdly, is a laboratory report which specifically answers the clinicians' question.

Both normal and pathological walking patterns are a combination of obvious and very subtle events. If the patient's gait deviations are simple, observation combined with the clinical examination may be sufficient. A drop foot following peroneal palsy is such an example. If, however, the patient's foot dysfunction follows a mixed nerve lesion (sciatic), stroke hemiplegia, cerebral palsy or head trauma, there can be considerable disparity between the clinical examination and the cause of the gait disability. Then observation alone is insufficient. To overcome this limitation, it is necessary that the

services of a gait laboratory be available to the clinician. In addition, to use this service the clinician will have to justify the need to the paying agency. Supporting documentation is scarce. There are two, possibly three publications which compare clinical and laboratory prediction of gait criteria for surgical planning. A study we are just completing compared the observational accuracy of experienced physical therapists to laboratory documentation. The data showed that trained observers varied in their accuracy, correctly identifying 35 to 70% of the events. More such material is needed.

Since Sutherland introduced the use of a gait laboratory for clinical planning and I followed with evidence supporting dynamic EMG as a presurgical planning procedure, numerous clinically oriented laboratories have evolved. Gage, working with Vicon has done much to standardize data documentation but much remains in the area of gait data interpretation. Simon has taken the lead in the development of automated gait data interpretation but his prototype is yet to be disseminated for clinical trial. In addition to this approach, considerable effort must be directed to determining which of the many possible analytical techniques specifically contribute to clinical planning and which are basically academic. Currently, the average clinician cannot interpret the typical laboratory gait report. Is it the volume, the complexity of the language or the inclusion of non-essential information in the interpretations?

A persistent challenge is to make more clinicians aware of the value of instrumented gait analysis to overcome the fact that observation combined with clinical examination remains the standard community practice. The interactions of the sequential yet asychronous joint motions of each lower limb are so complex that most clinicians compromise by memorizing the more obvious events and rejecting the subtle events as not significant. One example is the differential diagnosis of premature heel rise. Excessive ankle plantar flexion is the “obvious” answer, yet the cause may be excessive knee flexion with the ankle in dorsiflexion. Laboratory analysis is needed to identify the coexistence of knee flexion, ankle dorsiflexion and heel rise. What further educational demonstrations are needed to stimulate increased reliance on laboratory analysis?

Several technical areas also need to be addressed. Moments and powers are common calculations but seldom are the data related to a specific clinical question. Just how do these data help the clinician? Surface EMG is the preferred technique because the discomfort of skin penetration is avoided. While peak values are significant, timing is obscured by cross-talk. Amplitude setting is another surface EMG problem. The skin and fat interface produce variable transmission of the signal. This leaves in question the accuracy of muscle representation. Without clarification of these issues the clinical value of surface EMG will remain limited. While these technical questions will not be settled by workshop discussion, such an exchange would establish areas of investigation.

Problems

1. Patient assessment techniques

2. Treatment planning/implementation

3. Access limitations

4. Divergence in clinical and engineering agendas

5. Research objectives

6. Technical limitations

7. Data interpretation limitations

Recommendations to advance gait analysis in rehabilitation medicine:

1. Expand the number of studies which document improved patient care as the result of laboratory gait analysis compared to unaided clinical procedures.

2. Develop a diagnostic hierarchy of gait analysis procedures. Determine which elements of laboratory gait analysis specifically delineate the patient's functional problem and contribute to the choice of treatment.

3. For each of the major pathologies determine the clinical questions which gait analysis can help resolve.

4. Improve the selectivity of surface dynamic electromyography.

5. Advanced the development of automated gait data interpretation.

The Use of Gait Analysis Assessments in Treatment Planning and/or Treatment Implementation

David H. Sutherland, M.D.

Several things stand out in my mind about the 1977 workshop. First it was exciting to participate in a workshop along with many of the best recognized laboratories and investigators of the time. The discussions were stimulating and the presentations, provocative. Twenty-seven laboratories were listed in the handout for the participants. Without exception, all of the laboratories were interested in research, but a much smaller number were carrying out clinical studies. Jacquelin Perry, Sheldon Simon, Edmund Chao, Mary Pat Murray, Morris Milner, and David Sutherland were the invited speakers to kick off the workshop. My own lecture topic for the workshop was normal gait in children. I presented early results from our NIH sponsored study of children one to seven-years-of age, and then followed with individual case studies of subjects with, Duchenne muscular dystrophy and poliomyelitis.

The differences between the earliest gait workshop and the most recent one at Crystal City, Virginia were very great. In the first place the number of gait laboratories in the United States, Canada, and Great Britain has at least tripled. The three methods presented for collecting and analyzing kinematic measurements in the first workshop included, 1) cine film with digitization, 2) electrogoniometers, 3) reflective strips and strobe lights to measure joint angles. By contrast, at the conference in Crystal City, the methods of kinematic data collection and reduction have markedly narrowed with the use of reflective markers, CCD cameras, and computers as the most frequently employed system at this time.

In the discussion of the papers presented at the first conference, the physiologists were greatly concerned because they felt that they were not hearing enough scientific questions. They were afraid that there would be a rush to use the technology without clear cut aims. My view then, and still is that we need to have more carefully thought-out hypotheses to test, that we need to include more neurologists and physiologists in our research projects, and that we need to expand our clinical outcome studies to include multi center collaboration. At the latest workshop, there was a great deal more talk about inter-laboratory collaboration, pooling of data, and clinical outcomes studies. The contrast between the first and second NIH gait workshops was enormous.

In conclusion, it would be fair to say that technology has progressed enormously and has been refined to focus on techniques for rapid data collection; gait labs have flourished; and clinicians and researchers have begun a dialog to address questions that can only be answered by well planned, collaborative, outcomes-based studies. The results of the present Workshop indicate that those in the community believe that such an approach has the potential to move the study of gait to a higher plane.