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Abstract

Introduction

The purpose of this workshop was to develop and prioritize a set of recommendations pertaining to the role of gait analysis in enhancing the function of people with locomotor disabilities. The history of gait analysis research since 1890 was reviewed, including the series of meetings from 1970 to 1977 sponsored by NIH. Since that time, there has been a great improvement in gait data gathering techniques and data reduction methods. The current meeting was called by NCMRR to develop recommendations to facilitate the maturation of gait analysis as a rehabilitation medicine tool.

Methods

The Workshop design consisted of three discrete phases. The first phase involved participant orientation. This began prior to the workshop with the submission of participant personal statements. On the first day of the Workshop, six invited speakers oriented participants to pertinent issues. These presentations covered: 1) The use of gait analysis as a patient assessment tool, 2) the use of gait analysis assessments in treatment planning and treatment implementation, 3) factors which prevent the people with locomotion disabilities from accessing gait analysis. The second phase of the meeting involved the development of recommendations. It began by splitting the group of 65 active participants into three working groups. Each of the working groups had two co-chairs who facilitated the process of identifying and prioritizing recommendation categories and the formulation of specific recommendation(s) within important areas. Active participants received a copy of all recommendations at the end of phase two.

During the final phase of the workshop, participants prioritize the set of recommendations using a descending priority scale from 100 (highest priority) to 600 (lowest priority). During the months that followed the Workshop, an executive committee, consisting of the workshop coordinators and session co-chairs, developed a comprehensive report based upon an extensive review and analysis of workshop products.

Results and Discussion

Priority scores for the 37 recommendations ranged from 201 to 467. Each recommendation was assigned to one or more of five classes, which in order of priority were: 1) efficacy, outcomes, and cost effectiveness research (8 recommendations); 2) education (5); 3) clinical research (6); 4) definition, standardization and policy (12); 5) basic research, technical development (11). Support for research related to the efficacy, outcomes and cost effectiveness of clinical gait analysis, the causal link between structure and function, and activities related to education, training, and standardization were identified as priorities. Professional organizations and societies were charged with the responsibility of further synthesis of the workshop products. Finally, government agencies, industry, and professional organizations were challenged to work

cooperatively towards achieving advancements for the future use of gait analysis in rehabilitation medicine.

SECTION IV
DISCUSSION

4. A CONTEXT FOR INTERPRETATION

4.1 Scope of Participant Demographics

Before discussing the key priorities that emerged from the Workshop, it is important to review the context within which the Workshop took place, and in particular the background of participants. The majority of workshop participants were not funded by NIH to participate in the workshop, but rather were supported by their home institution or personal resources. This suggests that most participants had a *vested* interest in the outcome of the Workshop (i.e., were stakeholders, desiring to be part of the process). The analysis of participant titles and affiliations indicated that many of these individuals held leadership positions and also provided broad representation for many of the professional categories currently involved in using or developing gait analysis techniques. Therefore, it may be concluded that the set of prioritized recommendations is likely a comprehensive summary of expert opinions.

4.2 The Recommendations

The first Workshop goal was to develop a comprehensive set of recommendations related to the future use of gait analysis as a tool to enhance the lives of people having impairments and functional limitations of the locomotor system that cause disabilities. A Workshop format with three breakout groups was implemented. Each of the three groups was instructed to develop recommendations under one of the three focus topics: A) The use of gait analysis as a patient assessment tool; B) The use of gait analysis assessments in treatment planning and/or treatment implementation; and C) Factors which prevent the people with locomotion disabilities from accessing gait analysis. Contact between groups was extremely limited during the recommendation development sessions due to the dispersed proximity of the workrooms and the rigorous work schedule. In addition, the workshop coordinators placed no limitations on the number of recommendations that a group could develop and the duplication of effort between groups by the workshop coordinators.

Remarkably, the three groups generated nearly equal portions (A=12, B=12, and C=13) of the total number of recommendations. Each of the 5 recommendation classes contained at least one recommendation from each working group and each of the three highest prioritized recommendations within each class, except class 1 recommendations, came from different groups. This is remarkable considering the working groups independently developed recommendation categories and were asked to focus their efforts on different topics. While striking similarities were found between paired recommendations from different groups, the diversity of topics and issues represented by the entire set of recommendations is a considerable accomplishment.

4.3 Interpretation of Priority Scoring

The second Workshop goal pertained to the prioritization of the recommendations. In short, participants were asked to indicate, by numerical score, the relative level of importance (priority) of each recommendation. The Executive Committee speculates that participants utilized a combination of at least two factors to establish priority scores: The first and most obvious factor relates to the relative importance of a recommendation with respect to other recommendations. The second factor related to any perceived need to execute a series of recommendations in a sequential fashion. It can be argued that many of the recommendations are linked to a time continuum by one or more factors. For example, participants may have felt the need to establish a complete understanding of the benefits derived from gait analysis before one should begin teaching the art and science of the field. In this example, the educational component may have value equal to the issue related to understanding of benefits even though it received a lower priority score. In light of such factors, great care should be taken not to interpret high priority scores (recommendations of low priority) as being indicative of "bad" recommendations or recommendations having little value. The recommendations of higher priority (low priority scores) may simply need to be addressed first.

Several aspects of the Workshop were designed to develop a strong relationship between the priority scores and the final written recommendations. The Workshop was designed to allow little time for group discussions on the relative priority of recommendations. For example, participant knowledge of their assignment to one of the three working groups was minimized prior to the Workshop. The brunt of the recommendation development activities occurred in small groups under tight time constraints. The recommendation presentation and discussion sessions were designed to assist participants in reviewing the written recommendations. An attempt was made to minimize the definition or clarification of key recommendation concepts that extended well beyond recommendation text. One or two participants did take the opportunity to express strong opinions as to the importance of specific recommendations and their personal interpretations of recommendation statements during these sessions. However, these incidents were few in number and resulted in minimal discussion. Therefore, we believed that participant scoring patterns reflect their interpretations of the documented recommendations and that these opinions were influenced minimally by individual statements (lobbying efforts) and clarifications of recommendation text that have gone undocumented. This is an extremely important concept since the linking of the recommendations and priority scores is crucial to their present and future interpretation.

4.4 Overview of Future Opportunities

Another Workshop goal was to document the similarities and differences in participant opinions towards the set of recommendations in such a way that future opportunities could be readily realized. The most obvious opportunity area relates to the individual recommendations that consistently received high priority or low priority scores. A review of mean priority scores and scoring distributions indicates that several of the recommendations can be classified in this manner. In brief, high priority items require action plans (several of which are contained latter in this section) and the implementation of action plans related to recommendations of low priority should be considered only after considerable reflection. The distribution of some recommendation scoring patterns was flat or binomial in nature. These recommendations are indicative of excellent opportunities for further discussion and clarification on topics and action items over which there exists significant divisions in thought within the community of gait analysis professionals. For example, recommendation A12 (Scope of gait analysis) recommended a broadening of the scope of gait analysis to movement analysis. This recommendation was ranked 19 out of 37, i.e., there were 18 recommendations ranked higher and 18 lower. Yet it had 17 participants (26%) rank it as a very high priority and 32 participants (49%) score it under 250; yet 13 (20%) participants gave it a score over 500. Under such conditions, constructive dialogue between individuals with opposing opinions is clearly the vehicle of choice when resolution of these differences is desired.

Therefore, we propose the following action items.

4.4.1 Action Item #1:

The professional organizations and societies, of which Workshop participants are members, should consider developing opportunities (i.e., round table discussions, open debates, and advisory boards meetings) for the clarification and documentation of differences in opinion that exist between experts on pertinent recommendation topics.

4.5 Efficacy, Outcomes and Cost Effectiveness Research

The highest priority was assigned to research on the efficacy, outcomes and cost effectiveness of gait analysis. Perhaps a key reason was the "help us" concept: in an increasingly challenging health care environment, the need for research that objectively documents efficacy grows. In particular, the suggested key areas requiring research activity relate to the effects of gait analysis on treatment decisions and functional outcomes. The top recommendation states that:

> "Research must accomplish the following:
>
> 1. Compare and contrast the effectiveness of clinical practice in the presence or absence of gait analysis.
>
> 2. Identify which patient categories objectively benefit from clinical gait analysis.
>
> 3. Replicate the findings of efficacy, outcomes and cost effectiveness studies to determine whether the results from particular studies are consistent and generalizable."

In reviewing the recommended actions for the 6 recommendations in Class 3 that were in the top eight of all recommendations, 5 of the 6 suggest increasing support for research in fairly general terms. While one (C4), specifically recommends that funding be provided to Centers of Excellence to design well-controlled studies.

When assimilated, the following action item emerges.

4.5.1 Action Item #2:

Funding agencies should consider supporting research that addresses the general objectives of these 6 recommendations. Since the recommendations are not specific with regards to areas of impairment or pathology, target populations should be left fairly broad. Relatively high priority should be given to proposals addressing treatment decision making and functional outcomes. The members of study sections, who are charged with the evaluation of these proposals, should be encouraged to review the contents of this report prior to performing their reviews.

4.6 The Causal Link Between Structure and Function

The fourth and seventh highest scored recommendations were the only two recommendations within the Top 8 that were not from Class 3. Both A11 "Development of models to study the relationship between the observed abnormal gait, lower extremity structure, and underlying etiology" and B9 "Identify the relationship between impairments, functional gait limitations, and disability" emphasized a need to better understand the effect of physical impairments such as lower extremity malalignment or muscular weakness on the resulting deficits and compensations in lower extremity function during gait. Both recommendations contain suggestions that these objectives could be met in part with improved neuromusculoskeletal models of the locomotor system. They suggest a model-based theoretical framework that provides both measurement and predictive capabilities is key to understanding the "relationship" between lower extremity structure and function. Both recommendations also suggest that the development, validation, and implementation of these models requires an intimate link between the measurement of impairments and functional limitations in gait.

4.6.1 Action Item #3:

Funding agencies should strongly consider sponsoring research aimed at establishing the causal link between lower extremity structure and function during gait. This research should include development and refinement of neuromusculoskeletal models of the locomotor system and its components that are capable of explaining the causal relationship between lower extremity impairments and function during gait. This research should include gait analysis and other direct measures of impairments and gait function and be applicable to diverse patient populations.

4.7 Education/Training

Despite the fact that none of the education-based proposals (Class 5) were in the Top 8 and that the recommendation for consumer and patient education (C11) received a lower priority rating, Class 2 (Education) ranked second only to Class 3 as an overall priority. Additionally, quite a few of the Top 18 proposals included an education aspect, even if not the primary thrust. The bottom line is that there was a strong sense of need for better training of health professionals in quantitative gait assessment, particularly young clinicians. The recommended actions include multiple mechanisms for making this happen, including a direct recommendation that NCMRR in particular provide a funding mechanism for the development of educational teaching tools, and for a fellowship program explicitly in gait analysis.

4.7.1 Action Item #4:

Funding agencies should consider creating an explicit, coordinated mechanism aimed at the development, dissemination and evaluation of customized educational courses and materials related to gait analysis. Funding mechanisms should include not only initial development costs but also costs for evaluating, refining, and disseminating these materials.

4.8 Standardization

Each of the Work Groups generated one or more recommendations focusing on standardization issues. While it is quite clear that there exists a strong desire for standardization amongst the participants, there appears to be "multiple opportunities for standardization" (B5) and numerous suggested techniques for their development and implementation (see recommendations B5, C6, A12, A6, and C8).

Therefore, we feel the following action item is warranted:

4.8.1 Action Item #5

Funding agencies should create mechanisms for supporting standardization activities when these activities relate to agency goals. For example, the National Center for Medical Rehabilitation Research should consider supporting the standardization activities of professional organizations. This should occur when the lack of standardization in a given area is considered a barrier to the development of scientific knowledge needed to enhance the health, productivity, independence, and quality of life of persons with disabilities.

SECTION III
RESULTS

3. OVERVIEW

This results section contains a detailed description of the various forms of data obtained during the planning and execution of the Workshop. The primary purpose of this section is to provide sufficient information regarding the principal components of this Workshop to allow readers of these materials an opportunity to develop interpretations of these data that are grounded by fact. The authors have made every attempt to present these data in an unbiased yet analytical format.

3.1 Participant Demographics

The following participant demographics were obtained from the lists of invited speakers, co-chairs and workshop participants (n=71). This list was updated during the Workshop to include individuals who had not pre-registered for the Workshop. A review of workshop registration materials indicates only one of the 59 pre-registered participants was not able to attend the meeting and that one individual participated after registering on site. Workshop attendance was limited to the first day for several pre-registrants. These combined lists indicate 53 individuals were trained at a Doctoral level. There were: 22 Ph.Ds; 18 M.Ds; 1 M.D., Ph.D.; and 12 Ph.D., P.Ts. represented within this group. Thirteen individuals were trained at a Masters level. Of these, six participants were also trained as physical therapists. Three of the four participants having received training at a Bachelor level were physical therapists. Three individuals did not stipulate post-secondary school training.

Approximately 54% of the participants were affiliated with academic institutions. Of this group, 82% were individuals who appeared to come from clinical departments. Forty-two percent of the total number of individuals appeared to have primary appointments within non-academic entities supporting clinical or research activities. The number of clinical (21%) and research (21%) affiliations under this category were equally divided. Three percent of the total number of participants appear to have professional corporate affiliations where involvement in clinical or research activities could not be readily determined.

3.2 The Recommendations

Titles and identification codes of the 37 recommendations that were formulated by the participants of the Workshop are listed in Tables 1-3. The letter prefix in the code denotes the working group from which the recommendation originated (A, B, or C). Working groups A and B each generated 12 recommendations while working group C generated 13 recommendations. The complete text of each recommendation can be found in Appendix B.

Table 1

Recommendation identification codes and titles from working group A

Code	Recommendation Title
A1	Gait assessment and clinical decision making
A2	Gait assessment and functional outcome
A3	Is gait analysis efficacious in improving treatment outcomes?
A4	Accuracy, precision, and validity of movement analysis techniques
A5	Evaluation of clinical interventions using functional movement analysis and disability measures
A6	Development of standards for management of clinical movement analysis data
A7	Development of timely and objective methods of acquisition, reduction, and interpretation of movement analysis data
A8	Development of a system network for sharing movement analysis data
A9	Education and training of personnel involved in gait analysis
A10	Determinants of gait related pathology
A11	Development of models to study the relationship between the observed abnormal gait, lower extremity structure, and underlying etiology
A12	Scope of movement analysis

Table 2

Recommendation identification codes and titles from working group B

Code	Recommendation Title
B1	Expand the clinical application of gait analysis
B2	Gait analysis as a cost effective patient management tool
B3	Use of gait analysis technology as treatment
B4	Clinical motion analysis data bank with patient profiles
B5	Standards for reporting the results of clinical gait analysis
B6	Collaboration via telecommunication/telemedicine
B7	Improved sensors of neuromusculoskeletal activity in gait analysis
B8	Automated protocol for determining joint centers
B9	Identify relationships between impairment, functional gait limitations, and disability
B10	Toward routine utilization of gait analysis
B11	Educate clinicians in the use of gait analysis and treatment planning
B12	Effectiveness of gait analysis

Table 3
Recommendation identification codes and titles from working group C

Code	Recommendation Title
C1	Advance research evidence for the clinical utility of movement analysis across a broad range of pathophysiologies
C2	Scope and availability of gait analysis facilities
C3	Establish comprehensive gait analysis as a standard of care in pre-surgical decision making for ambulatory children with cerebral palsy
C4	Role of three dimensional computerized gait analysis in treatment decision making and as an outcome measure and its cost effectiveness
C5	Time /distance analysis for use in group/multicenter outcome studies
C6	Define the components of gait analysis
C7	The development of interactive software to assist professionals in the interpretation, synthesis, and use of locomotion data
C8	Standardization of gait analysis
C9	Accreditation of diagnostic clinical gait laboratories
C10	Medical education models for health care professionals
C11	Consumer and patient education
C12	Universal access to gait analysis services
C13	Development of information resources to help new gait labs

3.3 Recommendation Priority Scores

As described in the methods section, every participant in the Workshop was asked to score each of the recommendations in Tables 1-3 according to the following priority system:

100 Highest Priority
250 Moderate Priority
350 Average priority
450 Low Priority
600 Lowest priority

3.3.1 Descriptive Statistics

The scores from all 65 participants for every recommendation were tabulated. Basic descriptive statistics for all the recommendations are listed in Tables 4 and 5. The distribution of scores for each recommendation are shown in Appendix C. It is apparent that the distribution of responses varies widely between recommendations. There are largely overwhelmingly high scores (A3), approximately normally distributed scores (B6), widely divergent scores (A7), and overwhelmingly low scores (C3).

Table 4

Descriptive statistics for the priority scores of all recommendations.

Code	N	Mean	Median	TrMean	StDev	SEMean
A1	65	233.7	200.0	224.4	115.0	14.3
A2	65	233.3	200.0	227.8	112.9	14.0
A3	65	200.6	150.0	190.2	110.2	13.7
A4	65	258.3	250.0	251.5	124.0	15.4
A5	65	261.7	250.0	256.1	132.7	16.5
A6	65	285.4	300.0	278.8	127.6	15.8
A7	65	349.9	350.0	349.9	141.4	17.5
A8	65	382.3	400.0	382.2	111.7	13.9
A9	65	270.9	250.0	265.9	116.0	14.4
A10	65	270.5	250.0	263.2	130.8	16.2
A11	65	226.8	200.0	219.8	103.1	12.8
A12	65	282.9	250.0	276.1	166.2	20.6
B1	65	236.5	200.0	230.0	110.9	13.8
B2	65	265.9	250.0	259.2	122.0	15.1
B3	65	356.2	350.0	356.8	149.2	18.5
B4	65	294.7	295.0	289.1	145.7	18.1
B5	65	253.1	250.0	248.3	121.7	15.1
B6	65	371.3	350.0	371.3	121.2	15.0
B7	65	380.2	400.0	382.8	149.4	18.5
B8	65	466.7	500.0	476.4	130.8	16.2
B9	65	235.2	200.0	224.4	139.5	17.3
B10	65	313.2	300.0	311.2	131.6	16.3
B11	65	267.6	250.0	264.3	111.1	13.8
B12	65	207.8	175.0	198.9	112.0	13.9
C1	65	254.2	250.0	248.7	107.5	13.3
C2	65	306.4	300.0	303.3	126.7	15.7
C3	65	454.5	500.0	464.2	149.8	18.6
C4	65	222.2	180.0	214.3	117.9	14.6
C5	65	450.2	500.0	460.4	148.1	18.4
C6	65	261.6	200.0	252.6	148.6	18.4
C7	65	270.2	250.0	264.7	116.0	14.4
C8	65	292.4	280.0	288.2	141.6	17.6
C9	65	304.4	300.0	299.7	160.0	19.8
C10	65	285.3	260.0	278.7	136.3	16.9
C11	65	331.3	350.0	329.4	136.0	16.9
C12	65	331.4	325.0	329.5	148.6	18.4
C13	65	376.2	400.0	378.4	146.4	18.2

(N = number of respondents, Mean = Arithmetic Mean, Median, TrMean = trimmed mean [removing lowest and highest 5% of observations], StDev = standard deviation, SEMean = standard error of the mean.)

Table 5
Minimum, Maximum, first and third quartiles for the priority scores of all recommendations

Code	Min	Max	Q1	Q3
A1	100.0	600.0	150.0	300.0
A2	100.0	550.0	135.0	350.0
A3	100.0	570.0	100.0	250.0
A4	100.0	600.0	155.0	350.0
A5	100.0	600.0	150.0	350.0
A6	100.0	600.0	180.0	350.0
A7	100.0	600.0	205.0	450.0
A8	100.0	600.0	300.0	460.0
A9	100.0	600.0	177.5	350.0
A10	100.0	600.0	175.0	350.0
A11	100.0	550.0	150.0	295.0
A12	100.0	600.0	122.5	400.0
B1	100.0	550.0	150.0	300.0
B2	100.0	600.0	160.0	350.0
B3	100.0	600.0	200.0	500.0
B4	100.0	600.0	150.0	400.0
B5	100.0	500.0	150.0	350.0
B6	100.0	600.0	300.0	450.0
B7	100.0	600.0	250.0	500.0
B8	125.0	600.0	350.0	600.0
B9	100.0	600.0	117.5	300.0
B10	100.0	600.0	200.0	400.0
B11	100.0	500.0	200.0	350.0
B12	100.0	500.0	100.0	270.0
C1	100.0	600.0	170.0	350.0
C2	100.0	600.0	200.0	400.0
C3	100.0	600.0	350.0	600.0
C4	100.0	500.0	135.0	300.0
C5	100.0	600.0	350.0	600.0
C6	100.0	600.0	150.0	340.0
C7	100.0	600.0	200.0	350.0
C8	100.0	600.0	162.5	400.0
C9	100.0	600.0	172.5	400.0
C10	100.0	600.0	200.0	400.0
C11	100.0	600.0	250.0	400.0
C12	100.0	600.0	200.0	462.5

C13	100.0	600.0	275.0	500.0

3.3.2 Recommendations ranked by score

All recommendations are shown in Table 6 ranked by the mean priority score from all respondents (a low numerical score is indicative of high priority). The Table provides an immediate view of the most urgent recommendations that emerged from the Workshop. However, it is apparent that there are many duplications and overlaps in the individual recommendations and this issue is addressed in an analysis by "class" of recommendation in Section 4.

Table 6

Rank order of priority scores for all recommendations

Priority Ranking	Mean Priority Score	Code	Recommendation Title
1	200.6	A3	Is gait analysis efficacious in improving treatment outcomes?
2	207.8	B12	Effectiveness of gait analysis
3	222.2	C4	Role of three dimensional computerized gait analysis in treatment decision making and as an outcome measure and its cost effectiveness
4	226.8	A11	Development of models to study the relationship between the observed abnormal gait, lower extremity structure, and underlying etiology
5	233.3	A2	Gait assessment and functional outcome
6	233.7	A1	Gait assessment and clinical decision making
7	235.2	B9	Identify relationships between impairment, functional gait limitations, and disability
8	236.5	B1	Expand the clinical application of gait analysis
9	253.1	B5	Standards for reporting the results of clinical gait analysis
10	254.2	C1	Advance research evidence for the clinical utility of movement analysis across a broad range of pathophysiologies
11	258.3	A4	Accuracy, precision, and validity of movement analysis techniques
12	261.6	C6	Define the components of gait analysis
13	261.7	A5	Evaluation of clinical interventions using functional movement analysis and disability measures
14	265.9	B2	Gait analysis as a cost effective patient management tool
15	267.6	B11	Educate clinicians in the use of gait analysis and treatment planning

16	270.2	C7	The development of interactive software to assist professionals in the interpretation, synthesis, and use of locomotion data
17	270.5	A10	Determinants of gait related pathology
18	270.9	A9	Education and training of personnel involved in gait analysis
19	282.9	A12	Scope of movement analysis
20	285.3	C10	Medical education models for health care professionals
21	285.4	A6	Development of standards for management of clinical movement analysis data
22	292.4	C8	Standardization of gait analysis
23	294.7	B4	Clinical motion analysis data bank with patient profiles
24	304.4	C9	Accreditation of diagnostic clinical gait laboratories
25	306.4	C2	Scope and availability of gait analysis facilities
26	313.2	B10	Toward routine utilization of gait analysis
27	331.3	C11	Consumer and patient education
28	331.4	C12	Universal access to gait analysis services
29	349.9	A7	Development of timely and objective methods of acquisition, reduction, and interpretation of movement analysis data
30	356.2	B3	Use of gait analysis technology as treatment
31	371.3	B6	Collaboration via telecommunication/telemedicine
32	376.2	C13	Development of information resources to help new gait labs
33	380.2	B7	Improved sensors of neuromusculoskeletal activity in gait analysis
34	382.3	A8	Development of a system network for sharing movement analysis data
35	450.2	C5	Time /distance analysis for use in group/multicenter outcome studies
36	454.5	C3	Establish comprehensive gait analysis as a standard of care in pre-surgical decision making for ambulatory children with cerebral palsy
37	466.7	B8	Automated protocol for determining joint centers

3.4 Classification of recommendations

3.4.1 Basis for classification

Although the three working groups were given particular areas in which to concentrate their recommendations, there was inevitably considerable overlap in the topic areas of concern to the different groups. In order to generate a more global view of the outcome of the Workshop, the following 5 "classes" of recommendations have been identified by the Executive Committee (workshop coordinators and co-chairs).

Class 1	Basic Research and Technical Development
Class 2	Clinical Research
Class 3	Efficacy, Outcomes, and Cost Effectiveness Research
Class 4	Definitions, Standardization, and Policy
Class 5	Education

3.4.2 Listing of Recommendations by Class

A list of recommendations by class is presented in Tables 7a-e. Some recommendations have been given more than one classification due their multifaceted nature.

Table 7a
Recommendations within Class 1
(Basic Research, Technical Development)

Class 1	Code	Recommendation Title
Class 1	A4	Accuracy, Precision, and Validity of Movement Analysis Techniques
Class 1	A7	Development of timely and objective methods of Acquisition, Reduction, and Interpretation of Movement Analysis data.
Class 1	A8	Development of a system network for sharing movement analysis data
Class 1	A11	Development of models to study the relationship between the observed abnormal gait, lower extremity structure, and underlying etiology.
Class 1	B10	Toward routine utilization of gait analysis
Class 1	B3	Use of gait analysis technology as treatment
Class 1	B4	Clinical motion analysis data bank with patient profiles
Class 1	B6	Collaboration via telecommunication/telemedicine
Class 1	B7	Improved sensors of neuromusculoskeletal activity in gait analysis
Class 1	B8	Automated protocol for determining joint centers
Class 1	C7	The development of interactive software to assist professionals in the interpretation, synthesis, and use of locomotion data.

Table 7b

Recommendations within Class 2

(Clinical Research)

Class 2	Code	Recommendation Title
Class 2	A5	Evaluation of clinical interventions using functional movement analysis and disability measures
Class 2	A10	Determinants of gait related pathology
Class 2	B3	Use of gait analysis technology as treatment
Class 2	B9	Identify relationships between impairment, functional gait limitations, and disability
Class 2	C1	Advance research evidence for the clinical utility of movement analysis across a broad range of pathophysiologies
Class 2	C5	Time /distance analysis for use in group/multicenter outcome studies

Table 7c

Recommendations within Class 3

(Efficacy and Outcomes, and Cost Effectiveness Research)

Class 3	Code	Recommendation Title
Class 3	A1	Gait assessment and clinical decision making
Class 3	A2	Gait assessment and functional outcome
Class 3	A3	Is gait analysis efficacious in improving treatment outcomes?
Class 3	B1	Expand the clinical application of gait analysis
Class 3	B12	Effectiveness of gait analysis
Class 3	B2	Gait analysis as a cost effective patient management tool
Class 3	C4	Role of three dimensional computerized gait analysis in treatment decision making and as an outcome measure and its cost effectiveness
Class 3	C12	Universal access to gait analysis services

Table 7d

Recommendations within Class 4

(Definitions, Standardization, and Policy)

Class 4	Code	Recommendation Title
Class 4	A6	Development of standards for management of Clinical Movement Analysis data
Class 4	A12	Scope of movement analysis
Class 4	B4	Clinical motion analysis data bank with patient profiles
Class 4	B5	Standards for reporting the results of clinical gait analysis
Class 4	B6	Collaboration via telecommunication/telemedicine
Class 4	C8	Standardization of gait analysis
Class 4	C9	Accreditation of diagnostic clinical gait laboratories
Class 4	C2	Scope and availability of gait analysis facilities
Class 4	C3	Establish comprehensive gait analysis as a standard of care in pre-surgical decision making for ambulatory children with Cerebral Palsy
Class 4	C12	Universal access to gait analysis services
Class 4	C13	Development of information resources to help new gait labs
Class 4	C6	Define the components of gait analysis

Table 7e

Recommendations within Class 5

(Education)

Class 5	Code	Recommendation Title
Class 5	A9	Education and Training of personnel involved in Gait Analysis
Class 5	B10	Toward routine utilization of gait analysis
Class 5	B11	Educate clinicians in the use of gait analysis and treatment planning
Class 5	C11	Consumer and patient education
Class 5	C10	Medical Education models for health care professionals

3.4.3 Ranking of Classifications

The priority scores for all recommendations in each separate class have been averaged to indicate the relative priority of the five different classes. The results are shown in Table 8:

Table 8
Rank order of each class of recommendations

Rank	Class	Topic	N	Mean	sd
1	Class 3	Efficacy, Outcomes, and Cost Effectiveness research	8	241.4	41.4
2	Class 5	Education	4	288.8	29.4
3	Class 2	Clinical research	6	304.7	82.7
4	Class 4	Definitions, Standardization, and Policy	9	313.0	63.7
5	Class 1	Basic Research and Technical Development	10	331.4	72.2

These results indicate that two categories of "Efficacy, outcomes, and cost effectiveness research" and "Education" were regarded by the workshop participants to be the highest priority for future attention. The mean priorities were markedly higher than the other three classes and the standard deviation of the scores were relatively small (CVs of 17.1% and 10.2% respectively). The remaining classes showed lower scores all grouped within a range of approximately 27 points and characterized by large coefficients of variation 27%, 20%, and 21.8% for classes 2, 4, and 1 respectively.

The message from the workshop participants appears to be that demonstrating the efficacy of present techniques, and disseminating the results is a higher priority than creating new techniques, changing policy, or conducting clinical research. It must be pointed out however, that the majority of recommendations concerning *Efficacy, Outcomes, and Cost Effectiveness* research could themselves be described as *Clinical Research* projects.

3.4.4 Recommendation Ranking Within Each Class

The following tables show the ranking of recommendations within each class. These tables allow the reader to assess the sub-priorities of workshop participants within the overall class priority.

Table 9

Sub-priorities within the 1st Priority Class - Class 3:
(Efficacy, Outcomes , and Cost Effectiveness Research)

Sub Priority	Code	Priority Score	Recommendation Title
1	A3	200.6	Is gait analysis efficacious in improving treatment outcomes?
2	B12	207.8	Effectiveness of gait analysis
3	C4	222.2	Role of three dimensional computerized gait analysis in treatment decision making and as an outcome measure and its cost effectiveness
4	A2	233.3	Gait assessment and functional outcome
5	A1	233.7	Gait assessment and clinical decision making
6	B1	236.5	Expand the clinical application of gait analysis
7	B2	265.9	Gait analysis as a cost effective patient management tool
8	C12	331.4	Universal access to gait analysis services

Table 10

Sub-priorities within the 2nd Priority Class - Class 5:
(Education)

Sub Priority	Code	Priority Score	Recommendation Title
1	B11	267.6	Educate clinicians in the use of gait analysis and treatment planning
2	A9	270.9	Education and training of personnel involved in gait analysis
3	C10	285.3	Medical education models for health care professionals
4	C11	331.3	Consumer and patient education

Table 11

Sub-priorities within the 3rd Priority Class - Class 2:
(Clinical Research)

Sub Priority	Code	Priority Score	Recommendation Title
1	B9	235.2	Identify relationships between impairment, functional gait limitations, and disability
2	C1	254.2	Advance research evidence for the clinical utility of movement analysis across a broad range of pathophysiologies
3	A5	261.7	Evaluation of clinical interventions using functional movement analysis and disability measures
4	A10	270.5	Determinants of gait related pathology
5	B3	356.2	Use of gait analysis technology as treatment
6	C5	450.2	Time /distance analysis for use in group/multicenter outcome studies

Table 12

Sub-priorities within the 4th Priority Class - Class 4:
(Definitions, Standardization, and Policy)

Sub Priority	Code	Priority Score	Recommendation Title
1	B5	253.1	Standards for reporting the results of clinical gait analysis
2	C6	261.6	Define the components of gait analysis.
3	A12	282.9	Scope of movement analysis
4	A6	285.4	Development of standards for management of clinical movement analysis data
5	C8	292.4	Standardization of gait analysis
6	C9	304.4	Accreditation of diagnostic clinical gait laboratories
7	C2	306.4	Scope and availability of gait analysis facilities
8	C12	376.2	Development of information resources to help new gait labs
9	C3	454.5	Establish comprehensive gait analysis as a standard of care in pre-surgical decision making for ambulatory children with cerebral palsy

Table 13
Sub-priorities within the 5th Priority Class - Class 1:
(Basic Research and Technical Development)

Sub Priority	Code	Priority Score	Recommendation Title
1	A11	226.8	Development of models to study the relationship between the observed abnormal gait, lower extremity structure, and underlying etiology
2	A4	258.3	Accuracy, precision, and validity of movement analysis techniques
3	C7	270.2	The development of interactive software to assist professionals in the interpretation, synthesis, and use of locomotion data
4	B4	294.7	Clinical motion analysis data bank with patient profiles
5	B10	313.2	Toward routine utilization of gait analysis
6	A7	349.9	Development of timely and objective methods of acquisition, reduction, and interpretation of movement analysis data
7	B6	371.3	Collaboration via telecommunication/telemedicine
8	B7	380.2	Improved sensors of neuromusculoskeletal activity in gait analysis
9	A8	382.3	Development of a system network for sharing movement analysis data
10	B8	466.7	Automated protocol for determining joint centers

It is interesting that "Education" achieved it's ranking as the second most important class because there were no scores that were extremely high or none that were extremely low. In contrast, it can be noted from Tables 8 through 12 that some very high priority recommendations fall into classes which are, overall, considered to be of lower priority. Among these recommendations that deserve further attention are:

In the third ranking class:

B9	Score 235.2	Identify relationships between impairment, functional gait limitations, and disability
C1	Score 254.2	Advance research evidence for the clinical utility of movement analysis across a broad range of pathophysiologies

In the fourth ranking class:

B5	Score 253.1	Standards for reporting the results of clinical gait analysis
C6	Score 261.6	Define the components of gait analysis

In the fifth ranking class:

A11	Score 226.8	Development of models to study the relationship between the observed abnormal gait, lower extremity structure, and underlying etiology
A4	Score 258.3	Accuracy, precision, and validity of movement analysis techniques

3.5 Participant Scoring Patterns

The relatively high degree of variability associated with individual and classified groups of recommendations is a significant influential factor when interpreting results of the prioritization process. One of the sources of this variability is due to differences in individual participant and working group scoring trends and strategies. In general, participants tended to prioritize the recommendations within the numerically lower half of the scoring range (see Figure 1). The grand mean of all 37 recommendation priority scores (298.5, sd=130.3) indicates that the participants generally felt the collective set of recommendations merited a favorable (less than 350) priority rating. Participant mean priority scores for all recommendations ranged from 170 to 390. The large differences in standard deviation values (compare participants 45 and 57 in Figure 1) may be indicative of individualized differences in scoring strategies. An indication of such differences can be seen in Figure 2 where it is apparent that participants used dramatically different levels of resolution to denote differences in priority. For example, participant 26 utilized only three scores (100, 350 and 600) to prioritize all the recommendations. On the other hand, participant number 59 appears to have provided a unique prioritization score for each recommendation.

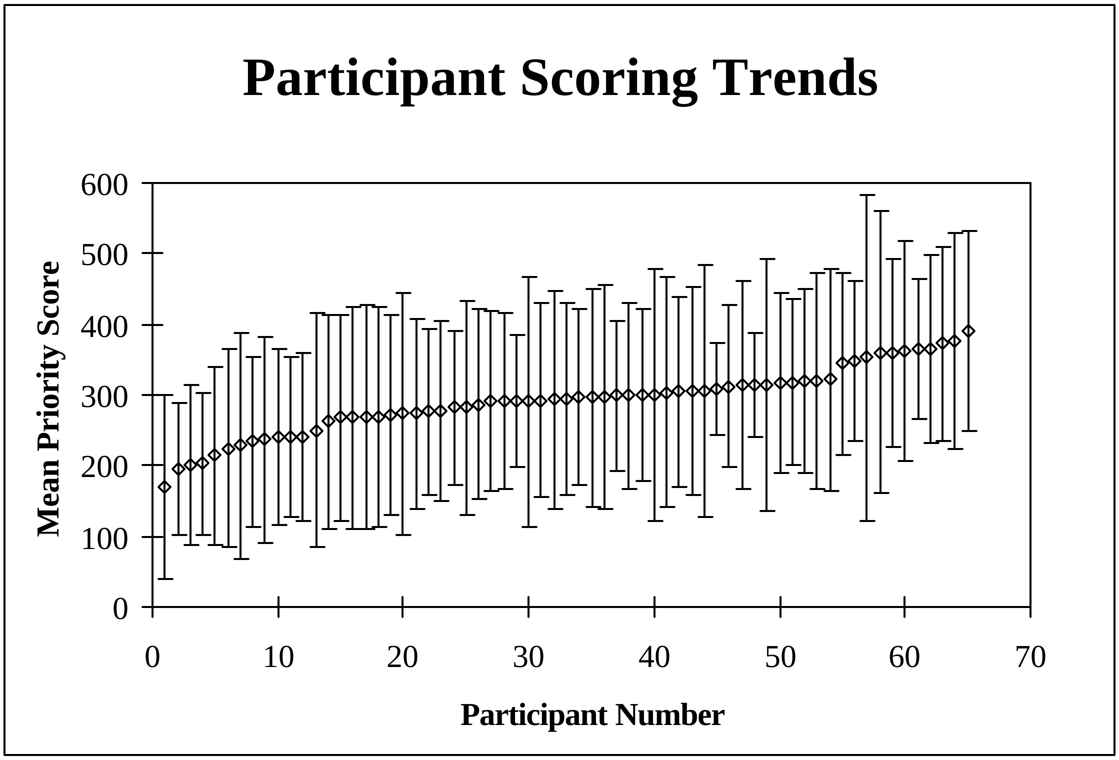

Figure 1: Mean (± sd) of recommendation priority scores for each participant. Participant data are arranged in ascending order of mean priority score values.

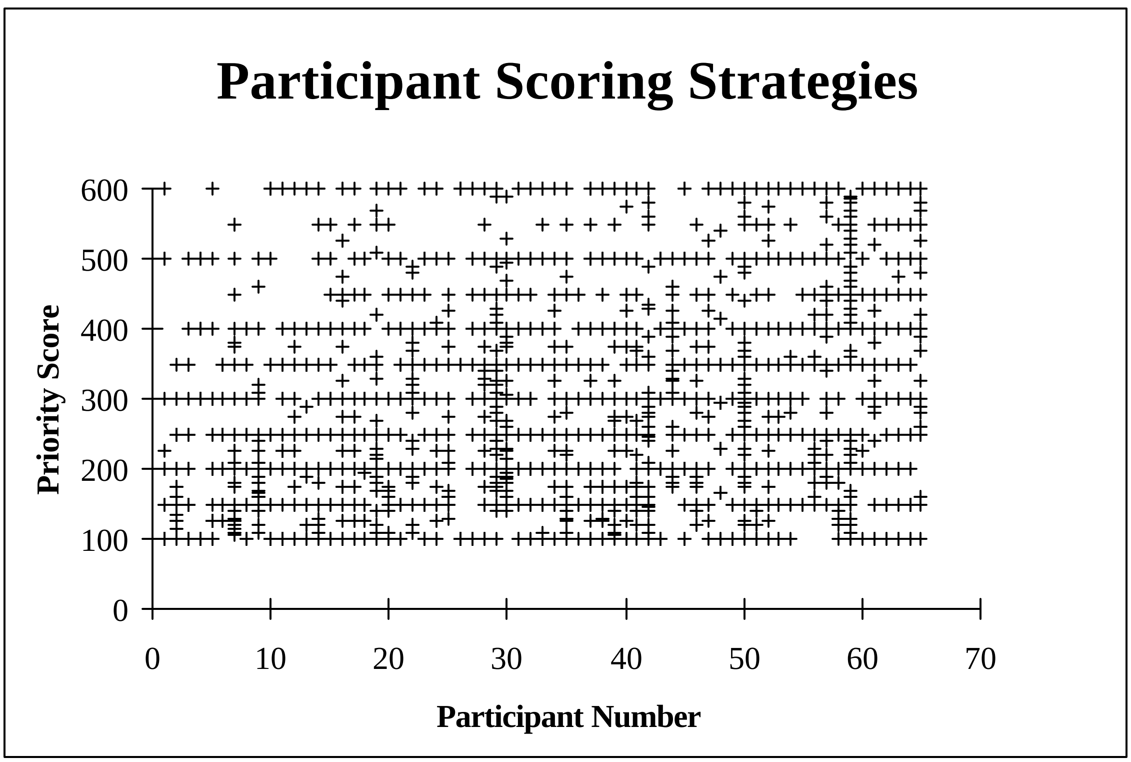

Figure 2: Scatter plot of the recommendation priority scores for each participant. Participant data are arranged in ascending order of mean score values.

3.6 Working Group Scoring Patterns

The mean priority scores for all questions formulated by each group (based on an average from the scores of all workshop participants) are shown in Table 14.

Table 14
Mean of scores assigned by all participants to the questions originating from each of the three working groups.

Recommendations from Working Group A			**Recommendations from Working Group B**			**Recommendations from Working Group C**		
A1	65	233.7	B1	65	236.5	C1	65	254.2
A2	65	233.3	B2	65	265.9	C2	65	306.4
A3	65	200.6	B3	65	356.2	C3	65	454.5
A4	65	258.3	B4	65	294.7	C4	65	222.2
A5	65	261.7	B5	65	253.1	C5	65	450.2
A6	65	285.4	B6	65	371.3	C6	65	261.6
A7	65	349.9	B7	65	380.2	C7	65	270.2
A8	65	382.3	B8	65	466.7	C8	65	292.4
A9	65	270.9	B9	65	235.2	C9	65	304.4
A10	65	270.5	B10	65	313.2	C10	65	285.3
A11	65	226.8	B11	65	267.6	C11	65	331.3
A12	65	282.9	B12	65	207.8	C12	65	331.4
						C13	65	376.2
Mean Score = 271.3 sd = 51.3			**Mean Score = 304.0 sd = 76.0**			**Mean Score = 318.4 sd = 71.1**		

3.6.1 Scoring Trends and Strategies

The influence of working group is an important factor to consider when evaluating the source of variability in participant scoring patterns. Working group activities were highly interactive amongst participants but not between working groups - interaction with other working groups was minimal and participants were not allowed to change groups. The role that facilitators played in stimulating group dynamics also varied. Therefore, it is likely that such interaction may have resulted in the development of group bias towards scoring techniques. Figure 3 indicates that the participant scoring trends within working groups A, B, and C were very similar. Indeed, the means for each group (A=288.2, B=307.9, C=297.6) were all very close to the grand mean of 298.5 for all participants.

The influence of working group on recommendation scoring strategies can be seen in Figure 4. It is evident that each working group produced a wide range of resolution in recommendation scoring patterns and thus appears as though differences in recommendation scoring strategies were strongly influenced by personal factors.

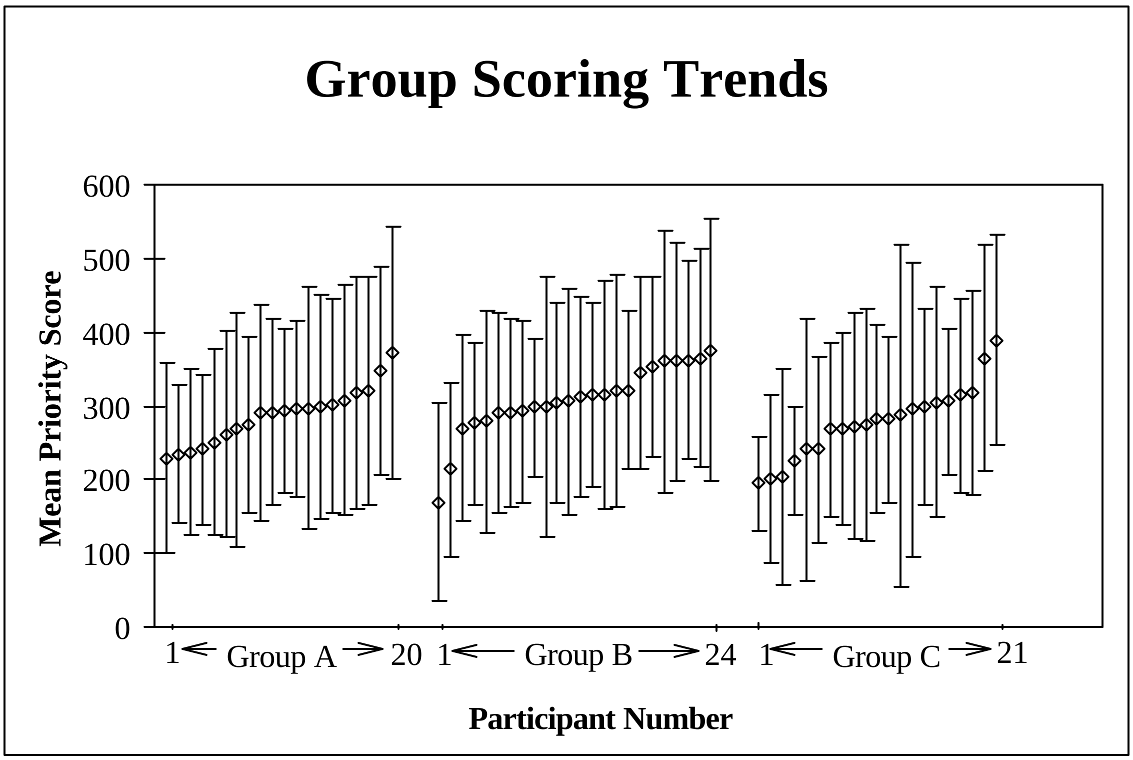

Figure 3: Mean (± sd) of recommendation priority scores for each participant sorted by group. Group data are arranged in ascending order of mean score values.

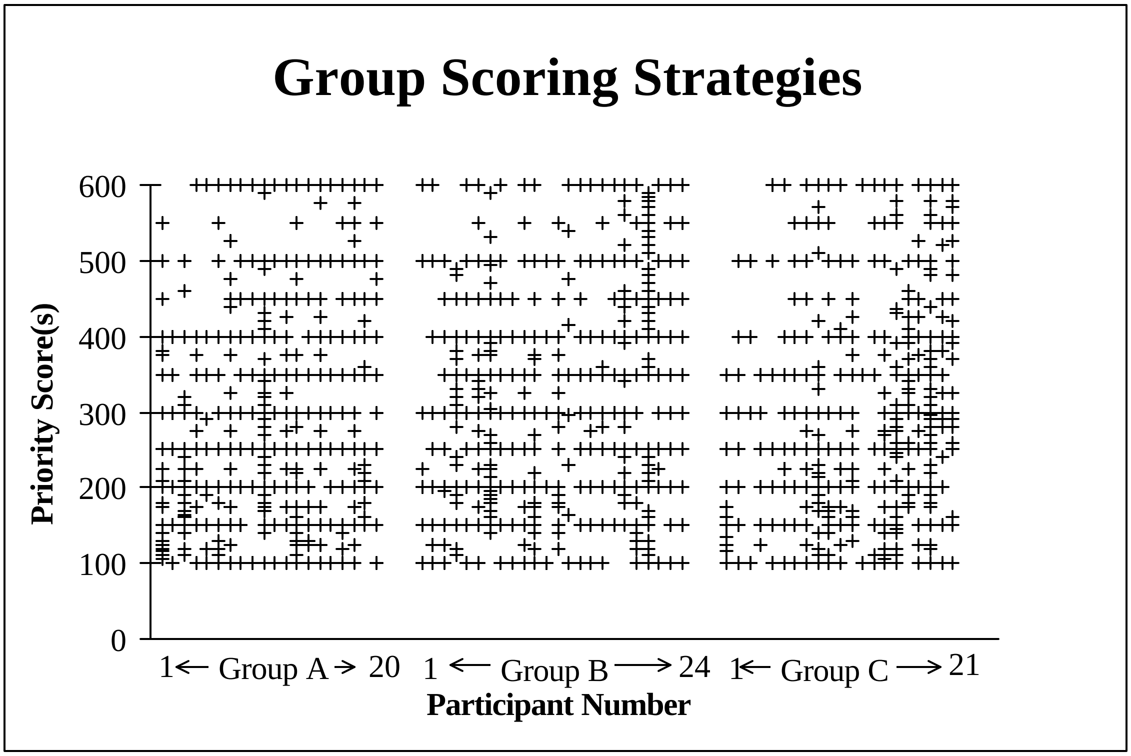

Figure 4: Scatter plot of the recommendation priority scores for each participant sorted by group. Group data are arranged in ascending order of participant mean score values.

3.6.2 Working Group Bias

Additional insight into the voting patterns of the three groups can be obtained from Figure 5. The recommendations have been organized into three categories depending upon which group formulated the recommendations (Group A recommendations, Group B recommendations, and Group C recommendations). The mean score given by the members of each group for all questions in a category are shown on the graph.

It can be seen that group 1 mildly favored their own recommendations (mean score of 21.7 points lower [better] than the next nearest other group); Group two showed no trace of bias (they scored their own questions 6.1 points higher [worse] than the next nearest group); Group 3 showed most bias (they scored their own questions 47.6 points lower [better] than the next nearest group).

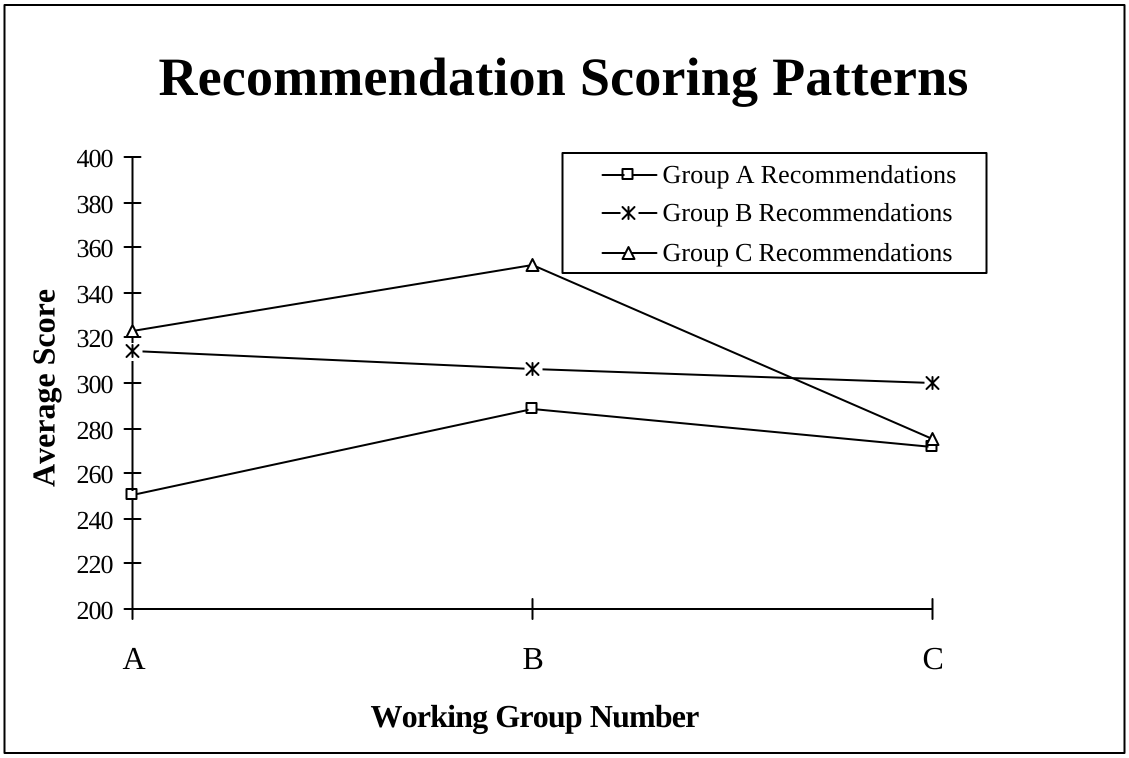

Figure 5: Voting patterns by group depending on the origin of the Recommendation

3.7 Workshop Evaluations

The results of a thorough evaluation of the Workshop's content and execution are an extremely important vehicle for providing information and feedback to workshop sponsors, designers, support staff, participants and readers of this report. Such information is helpful in evaluating participant enthusiasm for the workshop topic. This is very important to consider when reviewing the prioritized recommendations. Surely, the importance of the recommendations having the highest priority would be greatly diminished if the majority of participants felt the meeting and discussed topics were not useful. In addition, the results of this workshop evaluation may be beneficial during the development of improved workshop models and for the development of future workshop topics.

A total of 66 completed workshop evaluation forms were received. This is one greater than the number of participants and working group chairpersons that scored the recommendations. The following data are the results of an objective and subjective analysis of the completed workshop evaluations.

3.7.1 Evaluation items 1-3

Items 1-3 of the evaluation form related to the workshop usefulness, organization and the presentation of workshop materials. A clear majority (96%) of participants felt that the Workshop was extremely or very useful (Figure 6). Likewise, 97% of the respondents felt the organization and structure of the meeting was either excellent or good (Figure 7). While the presentation of workshop materials was rated high by 99% of participants (Figure 8), markedly fewer respondents rated this item excellent as was the case with evaluation items one and two.

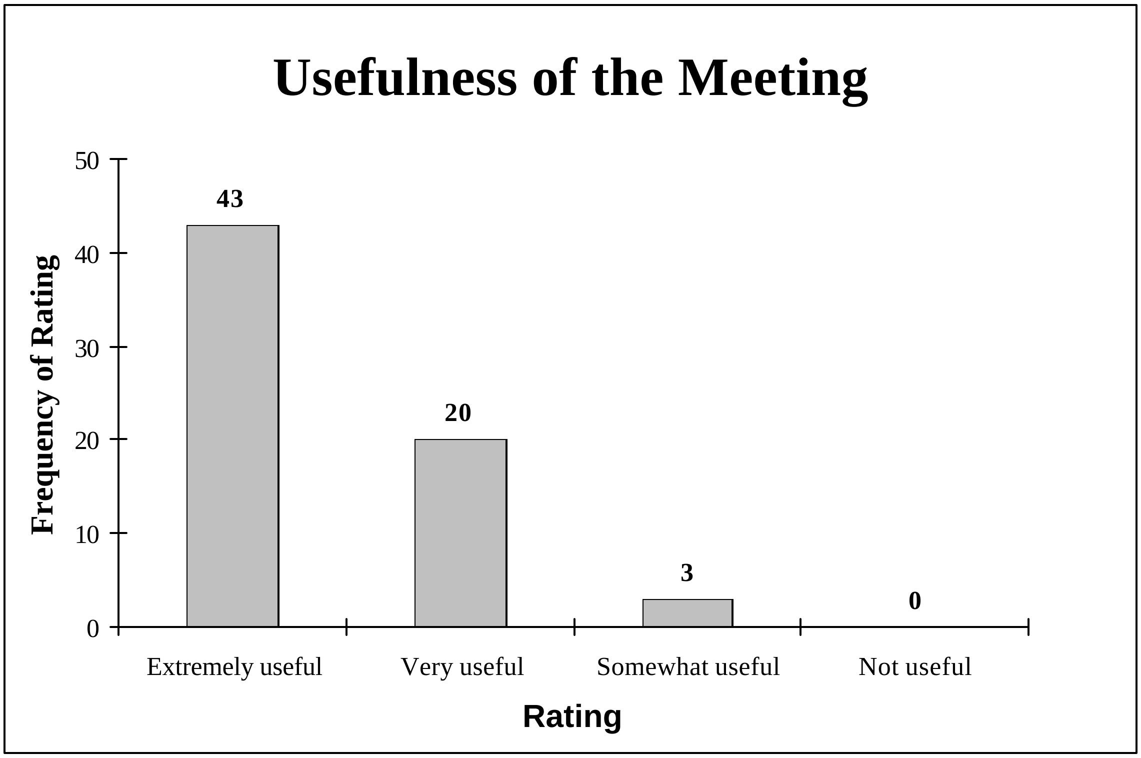

Figure 6: Histogram containing the frequency of participant responses rating evaluation item 1: Usefulness of the Meeting (and topics discussed).

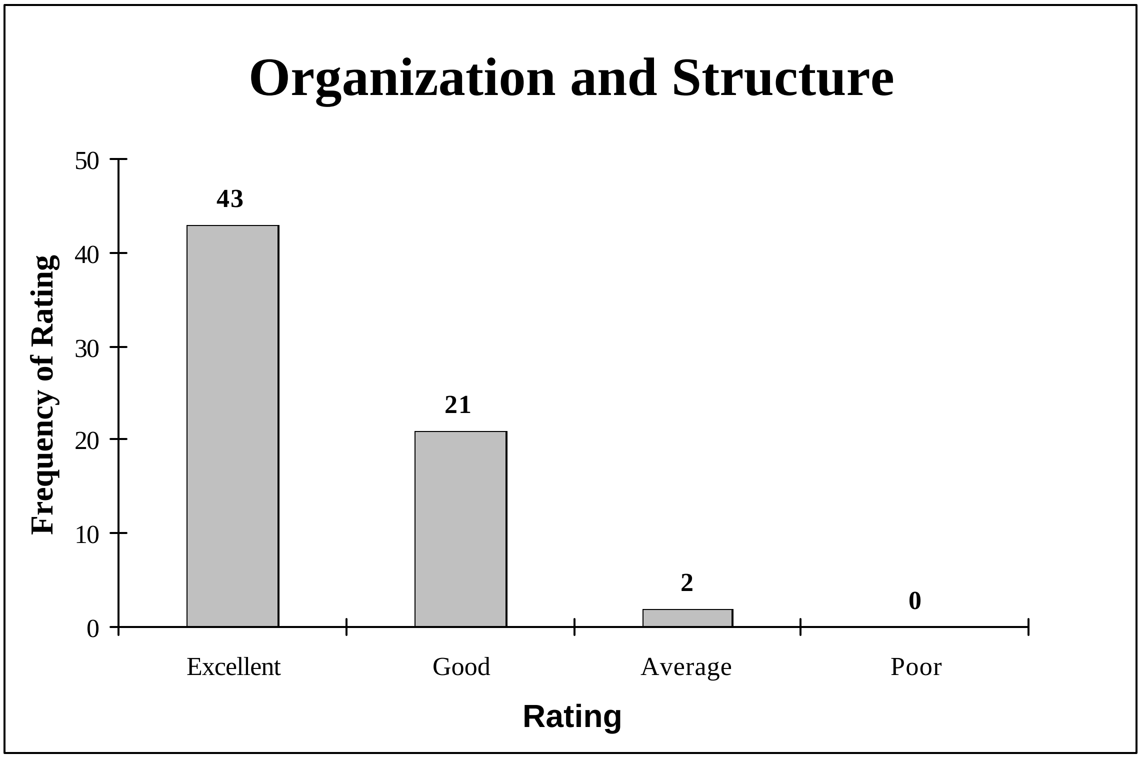

Figure 7: Histogram containing the frequency of participant responses rating evaluation item 2: Organization and structure of the Meeting.

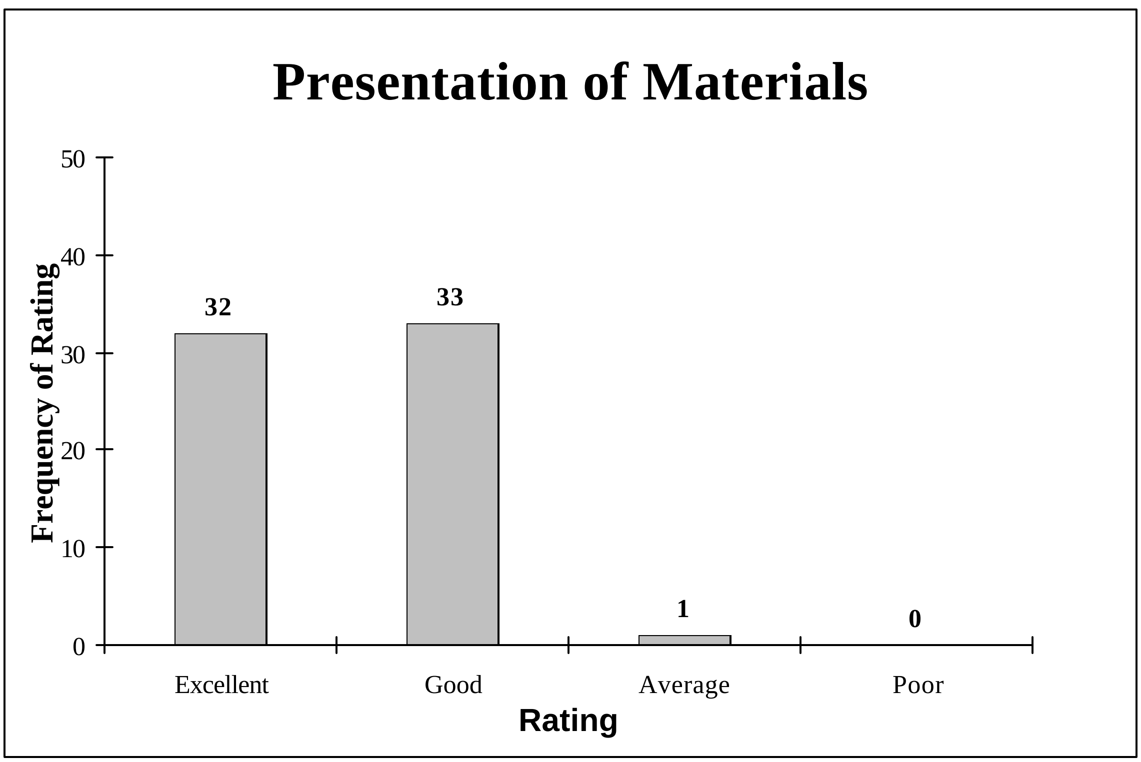

Figure 8: Histogram containing the frequency of participant responses rating evaluation item 3: Presentation of materials, (including handouts, slides, etc.).

3.7.2 Evaluation Items 4-8

The following is a summary of responses obtained from items 4-8 of the workshop evaluation form.

Question 4. What was the best part of the Meeting for you?

Enthusiasm of the participants, speakers and session chairs was considered the most positive aspect of the Workshop by the majority (42/66) of respondents. These individuals felt the participant interaction, small group meeting format, and personal atmosphere were the best parts of the meeting. While 17/66 felt that the best part of the Workshop was direct involvement and development in the future direction of gait analysis, the remaining 7/66 participants felt that the presentations and structure of the meeting were best. Examples of individual comments related to this evaluation item are:

> "Meeting others active in the field"
>
> "Interaction and the development of teamwork"
>
> "The open sharing of ideas and common problems in an atmosphere free from institutional constraints"
>
> "Getting a sense of what the priorities are to move the field of gait analysis forward"

Question 5. What was the weakest part of the meeting for you?

Limited time for the Workshop and group discussion was considered a weakness by 21/66 participants while 16/66 felt that there were no weaknesses. Lack of structure or organization and a slow printer for copies and distribution of meeting materials accounted for 9/66 and 4/66 replies respectively. The remaining group of 16/66 provided a range of comments such as:

> "Inadequate time to discuss ideas and generate collective statements"
>
> "The short amount of time to accomplish the task"
>
> "No chance to have input into other sections"
>
> "The lack of understanding by co-chairs in my department regarding direction and structure in the development process of problem areas"
>
> "Vagueness about what participants were supposed to produce"
>
> "Might have helped to have a bit of guidance about writing the recommendation for

those of us with less experience"

"I would have liked more rehab emphasis as opposed to ortho/engineering, but that is my personal area of interest"

Question 6. What improvements would you make if any?

Almost 33% (21/66) of responding participants felt that there were no improvements necessary. Increasing the duration of the Workshop was an improvement that 16/66 of the respondents suggested. Discussion of trends and controversies in gait analysis was viewed by 12/66 as an activity that should be included in future meetings. The remaining 17/66 noted varying suggestions for improvement such as:

"Try to increase opportunity for interaction between more individuals"

"Allow one more day for continued recommendation development"

"Presentations of conflicting ideas in and about gait analysis, biomechanics of movement, and clinical analysis could have been presented"

"Provide individuals with opportunity to make recommendations in areas beyond the scope of their assigned area"

Question 7. Do you have any Specific preferences for future meeting topics?

Specific preferences for future workshop topics was left blank by 41/66 responding while 25/66 covered a wide variety of topic requests such as:

"You could have a conference on any single or small area of the ideas recommended"

"A conference specific to the use of movement analysis for diagnosis, prescription, and evaluation of functional outcome and disability"

"Quality control of all aspects of gait"

"Controversies in gait analysis"

"Development of standards for management of clinical movement analysis data"

Question 8. Comments:

Greater than 50% (34/66) of those responding to the questionnaire had no further comments, 26/66 thanked and praised the organizers for a job well done, while the remaining 6/65 made helpful suggestions. The following is a list of representative statements:

“It has been an honor to be part of this distinguished group. Thank you very much for holding this conference”

“Despite poor advertising, the meeting attracted a large number of qualified colleagues. I am impressed by the overall organization and efficiency”

“Is there a mechanism to inform the participants of the status/action/in action regarding the recommendations”

“Excellent format, need to use a 2-step process to reduce number of recommendations”

SECTION II
METHODS

2. OVERVIEW

The Workshop design consisted of three distinct phases. The first focused on orienting co-chairs and participants to the task of developing recommendations. This phase began the evening prior to participant involvement with an orientation session for co-chairs. The goal of this meeting was to introduce co-chairs to the concept of team facilitation and overview detailed instructions pertaining to the recommendation development process. Co-chairs were provided an opportunity to review guiding philosophies and important definitions, practice warm-up activities, and discuss outlines describing the preferred recommendation development process. On the first day of the Workshop, participants received background material and a glimpse of the future of gait analysis by prominent speakers in the field of gait and human movement analysis.

The second phase was focused on recommendation development. One and a half days were spent in smaller working groups directed to develop recommendations for the future of gait analysis. Each of the three work groups were facilitated by co-chairs as they worked on one of the three topic areas. Work groups were subdivided into teams and groups were asked to develop concise recommendations using a model recommendation as a guide. On the last day of the meeting, verbal summaries of all of the recommendations were presented to the group at large.

Finally, after having an opportunity to review and briefly clarify each of the recommendations, each workshop participant was asked to assign a priority score to each recommendation (third phase, priority scoring), including those developed by other work groups. The recommendation scoring session could best be described as a scripted directed activity during which participants were instructed to score recommendations sequentially.

Immediately after scoring the recommendations, a team of Workshop participants entered the raw scores into a computer generated spreadsheet. While this was occurring, the Workshop coordinators and co-chairs met in an executive session to create a plan for the development of this document.

The following sections contain essential details related to the goals and principal phases of the Workshop.

2.1 Guiding Philosophies

The following is a list of guiding philosophies that was used to orient co-chairs during the co-chair orientation session.

1) We wish to capture all recommendation ideas, however unusual they might seem.
2) Participants, should be encouraged to be bold! There are no bad recommendations.
3) A comprehensive list of recommendations that covers many categories is best.
4) A large total number of recommendations is better than a few.
5) The basic philosophy of recommendation development is to strengthen all recommendations.
6) Duplication of effort between work groups is acceptable, encouraged, and an expected outcome of this meeting.
7) Sole authorship of recommendations is acceptable however discouraged. Co-chairs, should attempt to maintain a team format.
8) All participants will judge (be given an opportunity to score) all recommendations.
9) Recommendations will not be prioritized using coercion or undesired ejection from the pool of recommendations.
10) To score well (receive a low score), a recommendation must be clearly written, contain a compelling argument, and pertain to an important cross cutting issue.

2.2 Important Definitions and Rules

1) A work group consists of a group of participants that has been assigned one of the conference topics.
2) A team is a subset of a working group and should contain no greater than five participants.
3) A participant's assigned position is defined by their assigned work group, team, and seat. Co-chairs may request participants to return to their assigned position at any time.
4) Participants may not enter the assigned room of other working groups.
5) Subject to co-chair approval, team membership can change as recommendations develop.
6) Each team member should be prepared to act as a recorder or spokesperson.
7) A team must have a spokesperson at all times.

2.3 Workshop Agenda

Thursday, September 26th - Morning

Milestones for this Day: Provide overview of task and background information. Formulate teams and strategies for report generation.

7:30-8:30 **Registration**

8:30-8:45 Greetings: *Marcus Fuhrer, Ph.D., Louis A. Quatrano, Ph.D.*

8:45-9:00 Overview of meeting: What the next three days will be like.
Steven J. Stanhope, Ph.D.

9:00-9:15 **Topic I: The use of gait analysis as a patient assessment tool.**
Introduction and overview
Chairs: Peter Cavanagh, Ph.D. and Casey Kerrigan, M.D.

9:15- 9:45 Presentation 1:
Melanie Brown, M.D.

9:45-10:15 Presentation 2:
Kenton Kaufman, Ph.D.

10:15-10:45 **Break**

10:45-11:00 **Topic II: The use of gait analysis assessments in treatment planning and/or treatment implementation.**
Introduction and overview
Chairs: Jerry Harris, Ph.D. and Alberto Esquenazi, M.D.

11:00-11:30 Presentation 1:
Sandra Olney, P.T., Ph.D.

11:30-12:00 Presentation 2:
Felix Zajac, Ph.D.

12:00-1:30 **Lunch**

1:30-1:45 **Topic III: Factors which prevent the people with locomotion disabilities from accessing gait analysis.**
Introduction and overview
Chairs: Jack Winters, Ph.D. and Freeman Miller, M.D.

1:45-2:15 Presentation 1:
James R. Gage, M.D.

2:15-2:45 Presentation 2:
Edmund Y.S. Chao, Ph.D.

2:45-3:00 Working group assignments and directives: Conference attendees will be divided into three independent working groups. Each working group will be asked to formulate recommendations related to one conference topic.
Steven J. Stanhope, Ph.D.

3:00-3:30 **Break**

3:30-5:30 Breakout: Conference participants convene in working group areas. Review strategy for reaching conference goal. Subdivide into teams and select team leaders.

Friday, September 27th - Morning

Milestones for this Day: Develop team recommendations. Formulate working group reports. Distribute draft working group reports to conference participants.

8:30 Reconvene working groups: Develop recommendations.

11:30-1:30 **Buffet lunch**

5:00-5:30 Working group Co-chairs submit draft reports to Conference Coordinators.

5:30-7:00 **Dinner:** Distribute draft reports to all conference participants

<u>Saturday September 28th, - Morning</u>

Milestones for this Day: Present and discuss working group recommendations. Score all recommendations. Generate final report development plan. Present report development plan to NCMRR representative.

8:30-8:45	**Greeting:** *Rory A. Cooper, Ph.D.*	
8:45-9:15	Presentation of Recommendations: *Co-chairs*	Working Group (Topic) I
9:15-9:30	Discussion	
9:30-10:00	Presentation of Recommendations: *Co-chairs*	Working Group (Topic) II
10:00-10:15	Discussion	
10:15-10:30	**Break**	
10:30-11:00	Presentation of Recommendations: *Co-chairs*	Working Group (Topic) III
11:00-12:00	Discussion	
12:00-12:15	Priority voting/scoring: Conference participants score recommendations *Conference Coordinators*	
12:15-12:30	Closing remarks *Marcus Fuhrer, Ph.D., Louis Quatrano, Ph.D.*	
12:30-1:30	**Lunch**	
12:30 - 5:00	**Executive Session:** Co-chairs of the three working groups, and conference coordinators for the three working groups meet and formulate development plan for the conference report to be presented to the NCMRR.	

2.4 Overview of Speaker Abstracts

The following abstracts were provided by speakers in advance of the conference. Each invited speaker was instructed to develop a presentation based on a predetermined topic or theme. Session co-chairs were invited to provide an overview of the session's topic as an introduction to main speakers. These presentations and associated materials were designed to stimulate participant interactions regarding fundamental issues pertaining to the use of gait analysis in Rehabilitation Medicine in the hope that this would facilitate the development of recommendations. We are grateful to the authors who have summarized their materials and made them available in a timely manner.

2.4.1 TOPIC I The use of gait analysis as a patient assessment tool.

Gait Analysis in Rehabilitation

Peter R. Cavanagh, Ph.D.

The field of clinical gait analysis still needs to respond to the challenges that have been posed by Brand and his associates (Brand 1992, Brand and Crowninshield 1981). Among the most important of the several criteria that these authors have proposed is the question: "Does gait analysis change the course of treatment and the outcome for the patient?" If this question cannot be answered affirmatively by carefully controlled, prospective, randomized, clinical trials, then the motivation for treating physicians and surgeons to order gait analysis will be significantly reduced.

There is also a need to define the scope of gait analysis in rehabilitation somewhat more broadly than has been done in the past. In addition to the conventional tools of electromyography and movement analysis, the measurement of such quantities as plantar pressure between the foot and the shoe, force between a walking aid and the hand, long term measurement of load bearing during activities of daily living all deserve consideration as valid components of gait analysis in a rehabilitation setting. While level straight line walking has been the paradigm of choice in most previous studies, renewed emphasis on other more demanding tasks of daily life should be given consideration.

It is critical that the technology of the information age be applied to the interpretation and management of clinical gait analysis data. With appropriate standardization of methodology, there should be no need for each laboratory to collect their own normative data. Such databases should be readily available electronically and the professional organizations should be taking a leadership role in the creation, distribution, and maintenance of such resources.

Brand, R.A. and Crowninshield, R.D. (1981) Comments on criteria for patient evaluation tools. Journal of Biomechanics, 114:655.

Brand R.A. (1992) Assessing gait analysis for clinical decisions. Proceedings of the VII Meeting of the European Society of Biomechanics, Rome. 256-259.

A Framework for the Use of Biomechanical Gait and Movement Analysis as an Assessment Tool in Rehabilitation Medicine

Melanie Brown, M.D.

Thirteen of the twenty-nine research priorities identified in the 1993 "Research Plan for the National Center for Medical Rehabilitation Research" require or would benefit from the use of biomechanical gait and movement analysis as an assessment tool. These research priorities involve the measurement of pathophysiology, impairment, functional limitation, disability, and societal limitation. The National Center for Medical Rehabilitation Research (NCMRR) defines pathophysiology as the interruption of, or interference with, normal physiological and developmental processes or structures. Impairment is a loss or abnormality at the organ or organ system level of the body. Functional limitation is the restriction or lack of ability to perform an action in the manner or within the range consistent with the purpose of an organ or organ system. Disability is a limitation in performing tasks, activities, and roles to levels expected within physical and social contexts. Lastly, societal limitations are restrictions attributable to social policy or barriers which limit fulfillment of roles or deny access to services and opportunities associated with full participation in society. Among the various measurement tools that are currently used in rehabilitation medicine, biomechanical gait movement analysis is one of the few assessment tools (if not the only one) that quantifies the functional limitations associated with pathophysiologies and impairments of the neuromusculoskeletal system.

Biomechanical gait and movement analysis is an assessment tool which is used to identify and measure biomechanical strategies. If the parts of the body are defined as segments (e.g., foot, shank, thigh, pelvis, trunk, etc.), then a biomechanical strategy is the series of segment positions and intersegmental moments (rotational forces) that is coordinated by the central nervous system in order to allow individuals to perform functional tasks. Each biomechanical strategy has a kinematic component (segment positions) and a kinetic component (intersegmental moments). Although the kinematic strategy may be readily observable, accurate identification of the kinetic strategy through visual inspection is rare. Zajac (1993) has described skeletal muscles as the active moment generators within the human body. He has pointed out that because the segments of the body are linked by joints (e.g., ankle, knee, hip, etc.), each muscle in the body has the capacity to apply a moment to any segment of the body; even segments to which the muscle does not directly attach. This implies that there are numerous kinetic strategies for executing any given functional task. There is mounting evidence that this redundancy in the neuromusculoskeletal system allows individuals with functional limitations to compensate through the use of adaptive biomechanical strategies (e.g., Siegal 1993). This is extremely important in rehabilitation medicine where a major focus is the prevention of disability and societal limitation through the use of assistive devices, exercise and other modalities which help patients compensate for functional limitations associated with neuromusculoskeletal abnormalities.

According to data from the 1989 National Health Interview Survey Supplement, there are at least 7.7 million American Adults (18 years or older) living in the community with disabilities. Within this disabled population it is estimated that 760 thousand individuals have difficulty getting out of a bed or chair, 2.4 million individuals have difficulty walking, and 2.2 million have difficulty going outside, presumably due to obstacles such as stairs. It is imperative that rehabilitation scientists and health care providers find better and more efficient ways of compensating for functional limitations in order to decrease the prevalence of disability and societal limitation in this population. Biomechanical gait and movement analysis has contributed to our understanding of functional limitations and how they relate to pathophysiology, impairment, disability, and societal limitation. Its continued use as an assessment tool in rehabilitation medicine is essential to accomplishing the research priorities outlined by the NCMRR and to enhancing the quality of life for people with disabilities.

RECOMMENDATIONS:

1. Perform randomized controlled studies in which a traditional rehabilitation intervention program is compared to a program designed using biomechanical movement analysis.
2. Compare rehabilitation outcomes in similar patient populations with and without the use of biomechanical movement analysis (blinded, randomized, controlled trials).
3. Decrease or subsidize the cost of the necessary equipment (force plates, cameras, computer software, and hardware).
4. Minimize the time it takes to collect, reduce, and analyze data.
5. Determine which scaling and statistical methods are most appropriate for reporting biomechanical movement analysis data.

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Future Directions of Gait Analysis as a Patient Assessment Tool

Kenton R. Kaufman, Ph.D.

During the past decade health care delivery systems have evolved at a pace that few expected. The most visible change is the development of managed care delivery systems. Managed care makes fixed payments per subscriber for all services, creating the incentive to attract a higher number of subscribers but provide the fewest number of services to each subscriber. Gait laboratories can play a key role in managed care scenarios. Future challenges exist to further evolve the science of clinical gait analysis to make it effective as a patient assessment tool. The future of gait analysis will depend upon advances made in experimental, analytical, and interpretation techniques for gait studies.

Experimental Techniques: Interest in gait analysis is emerging. Despite the growing availability of technology, gait analysis has not yet become a common tool for the clinician. The future of gait analysis lies in the ability to process data quickly and identify the functional problems of a patient's gait. Currently, the manual labor required to sort and identify the trajectories which describe the patient's motion for each individual trial is time consuming, driving the cost of the analysis up and slowing down the turnaround time for clinical decision-making. Future work needs to be undertaken to develop intelligent tracking systems of multiple markers which will provide measurements in real time within the constraints of accuracy, resolution and high scan rates required for clinical analysis without constricting the already limited function of a severely disabled child or adult.

The results of the gait study must be presented in a form which is readily comprehensible. Currently the clinical interpretation of pathological gait requires holding in human memory a large number of graphs, numbers, and clinical tests from data presented on hardcopy charts, radiological x-rays, video, and computerized graphs which are compared to data from a normal population. The referring physician, who is not an expert in gait analysis, is overwhelmed by the portfolio of measurements in a clinical report. Recent developments in computer animation make it possible to apply advanced methods to visualize human movements a scientific computing environment is needed which will allow the rapid transmission, archival, retrieval, and manipulation of images within a system which is intuitive to a clinician.

Analytical Techniques: During a gait study, a large number of measurements are obtained. The experimental data are entered into an analytical model to obtain values of variables not directly measurable. The body is modeled as a system of articulated, rigid links. The joint rotation is based on the determination of Eulerian angles or the screw displacement axis. The joint motion is combined with the ground reaction force, body segment mass and body segment inertia to compute the intersegmental joint kinetics using Newton's second law. These body segment estimates are a big source of error in biomechanical models. Future work should be aimed at obtaining inexpensive, fast, non-invasive, individualized estimates of the inertial properties of body segments. In addition, realistically developed, theoretical models of the musculoskeletal system are needed to quantitate biomechanical changes which may occur in patients as a result of surgery prior to the performance of the surgery. Currently, state of the art mathematical models of the musculoskeletal system are being developed to predict gait patterns. Future models should include the 3-D characteristics of the musculoskeletal geometry as well as the subject-specific parameters. The musculotendinous aspects of the model need to be scaled to the individual being studied. The biomechanical consequences of modifying muscles or bones needs to be estimated in a computer environment and presented to the clinician to actually see the results of the proposed surgical intervention.

Muscle forces reflect the underlying neurological control processes responsible for observed movement patterns and play a major role in determining stress in bones and joints. Thus, a knowledge of muscle forces is fundamental for improving the diagnosis and treatment of individuals. Currently, information on muscle function is routinely obtained by acquiring electromyographic data. However, the integrated electromyogram does not account for the passive stretch of muscle. Further, there is a significant delay between the maximal electrical activity in the muscles and maximal tension. An attractive alternative for quantification of muscle function is the measurement of intramuscular pressure which is a mechanical variable that is proportional to muscle tension. Further, estimation of muscle force from intramuscular pressure is not affected by changes in signal due to muscle fatigue. However, currently available transducers for measurement of intramuscular pressure are too large for clinical applications. Recent improvements in micro sensor technology will make it possible to develop much smaller, minimally invasive devices.

Interpretation Techniques: Methods are needed to characterize a patient's gait and direct the clinician reading the gait study to the movement abnormalities. A person's gait is classified as abnormal when the person's gait parameters deviate excessively from normal. One of the main obstacles to automated gait analysis is the difficulty of distinguishing between normal and abnormal. Robust analysis of these data require consideration of interactions among a large number of highly coupled variables and the time dependence of these variables. Statistical techniques and artificial intelligence techniques have been utilized for recognizing gait abnormalities. Each of these methods offers advantages and disadvantages. Additional development of these techniques is needed.

Summary: The ultimate goal of clinical gait analysis is to provide reliable, objective data upon which to base clinical decisions. Real-time measurement technology, biomechanical modeling, computer animation, and gait classification techniques are needed to shape our future. It is increasingly important that we consider the effectiveness of what we do and the role it plays in shaping outcome of medical care. The future of gait analysis will require the ability to identify the critical tests, obtain and interpret data more quickly, predict the outcome of various clinical procedures and quantify the outcome. Reforms in health care require that we be able to manage costs while providing an important diagnostic service.

2.4.2 TOPIC II The use of gait analysis assessments in treatment planning and/or treatment implementation.

Summary to Introduction and Overview for "The Use of Gait Analysis Assessments in Treatment Planning and/or Treatment Implementation."

Jerry Harris, Ph.D.

The purpose of this introduction is to provide a brief overview of gait analysis applications as they apply to treatment planning and implementation. Gait analysis has proven useful for the study of neuromuscular disorders, the evaluation of prosthetic joint replacement, and the study of athletic injuries, amputee gait, orthotics, and assistive devices. The most prevalent of applications is in the field of pediatric orthopaedics where gait analysis is used for pre-surgical planning, post-surgical follow-up, evaluation of surgical and non-surgical interventions, resident training and research.

This introduction will focus on the use of quantitative gait analysis methods for treatment planning and implementation. The recognized prerequisites of normal gait will be defined and used to examine the advantages and limitations of current gait analysis methods. Several clinical illustrations that require the identification of multiple bone and soft tissue abnormalities for proper treatment will be highlighted. Examples of clinical conditions requiring an ability to examine multi-level, simultaneous events in three dimensions in order to differentiate between primary deviations and coping responses will be presented. The use of joint kinetics (moments and powers) to assist in treatment planning and orthotic evaluation will also be included. Finally, the importance of a combined clinical approach which includes kinematic and kinetic gait analysis, dynamic electromyography and clinical examination will be summarized.

Gait Analysis in Treatment Planning and Implementation: Good, Bad and Indifferent, but Which are Which?

Sandra J. Olney, P.T., Ph.D.

Gait assessment over the past several decades has contributed greatly to our knowledge about walking but a great deal has been written about its failure to be an essential tool in treatment planning and implementation in rehabilitation. I am not going to complain about high costs of unreliable equipment, unwilling health care providers, the failure of clinicians to understand biomechanics, and the failure of engineers to ask the right questions. Instead, there are good, bad, and indifferent applications, and I will provide my assessments for discussion.

Of **spatial-temporal measures**, walking velocity is arguably the single most important outcome measure of walking, and relates significantly to most functional measures. It has not been used directly in treatment planning. Many other measures, such as temporal and spatial symmetry, have been expressed in a number of ways, and some evidence suggests symmetry is not very important (Griffin et al., 1995). In summary, such measures document the status of a subject and offer little for treatment planning. The applications of spatial-temporal measures have been of indifferent merit at best.

Treatment planning has frequently focused on obtaining more normal joint kinematics, such as increasing dorsiflexion of the ankle during swing phase or avoiding genu recurvatum. In general, if the desirability of specific joint patterns is self-evident, as in preventing tripping, or avoiding genu recurvatum, kinematic assessment has proved to be very useful both in planning and evaluating treatments. However, altering the kinematics in the direction of normal without a specific reason may be deleterious, for example, by preventing a positive adaptation (Winter et al., 1990). In summary some applications of kinematic measures from gait analysis are good, but many have been of indifferent merit, or even bad.

The evaluation of **kinetic information** is most difficult as it is the latest reported, a fact that may be attributable to the sophistication and expense of the analysis systems required. Overall, measures of movements have rarely been used to plan treatment. The muscle powers across major joints have been reported for a few conditions and some theoretically-founded recommendations for treatment planning have been offered (Olney and Colborne, 1991). The use of emerging general principles, such as attempting to augment the power generation of the ankle plantarflexors at push-off (Mandel et al., 1990) have generally given positive outcomes, though the failure to report kinetic details limits the ability to make full use of the studies. In summary, general principles of treatment are being put forward for some pathologies, but much more work is needed; applications of kinetic measures to treatment have generally been absent , though their potential appears good.

What is needed to make gait analysis useful for treatment planning and

implementation?

Stop making assumptions about the desirability of normal patterns of any measures. Offering information that is indifferent or bad is worse than offering no information, and only damages the credibility of that method.

Use more kinetic analysis. It is logical to target the source of the problems.

Establish sound biomechanical principles of treatment applying to particular pathologies.

Verify the principles of treatment and determine the extent of their generalizability. Only the most obvious of principles have been identified and even these have not been thoroughly studied.

Relate outcome measures such as gait velocity to specific kinetic changes. Failure to do so impairs our ability to target specific kinetic variables in treatment and to use them to develop innovative therapy.

Develop power, work and efficiency measures for use in meaningful ways. Energy is a paramount concern, and our tools are seriously deficient.

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Using Musculoskeletal Models, Forward Dynamics, and Computer Simulations to Analyze Gait, Interpret Gait Data, and Plan Treatment

Felix E. Zajac, Ph.D.

The following is what is needed at a basic level to make gait analysis a highly productive tool:
-Development of a conceptual basis for how muscles coordinate the body segments
-Development of methods to measure muscle/tendon force or muscle/tendon motion during gait
-Development of a conceptual framework for sensorimotor control of muscle coordination

Human gait demands that the nervous system (because of its role in coordinating muscles) and the musculoskeletal system (because of its role in producing muscle forces, body acceleration, and movement) interact effectively, not only amongst themselves, but with the environment. That is, the nervous system has the role of being the sensorimotor controller, the musculoskeletal system the role of transforming neural output signals from the controller into forces, and the environment the role of resisting gait propulsion (e.g., wind resistance) or assisting propulsion (e.g., the ground from which reaction forces propel the body). Pathology in either the neural or musculoskeletal system can cause gait impairment, which may or may not be a disability.

The primary obstacle to effective utilization of current gait measurements in the diagnosis, treatment, and assessment of gait disorders (especially those from neural pathology) is the absence of a theoretical foundation from which basic concepts of sensorimotor control and muscle coordination can evolve. Minimally, the fundamental unitary element of these concepts must be at the muscle level (cf. Joint level). Other obstacles are experimental in nature; the inability to record data at the muscle level (e.g., muscle forces; difficulty of recording from individual muscles with surface electrodes; technical expertise of using fine-wire electrodes) and to design experiments from which sensorimotor control principles can be elucidated.

The current conceptual framework of muscle coordination in human gait is, in a large part, not based on the integrative action of individual muscles to coordinate individual body segments, but rather on knowledge of how each musculoskeletal component functions alone. For example, basic concepts of how muscles develop force and interact with loads exist (though they may not be the loads encountered during locomotion). Concepts of how tendons stretch when loaded and how the musculotendon path around the joint affects the transmission of muscle force into joint torque (or moments of muscle force about the joint) also exist. We even know how the body segments interact in the swing leg and how legs (if considered to act like springs) can propel animals and can account for the kinetic and potential energy flow of the whole body. But we know very little about how the properties of these individual elements of the musculoskeletal system coordinate body motion to produce gait. The integrative action of muscles in coordinating movement of the body segments is critical to the understanding of gait since a muscle can accelerate body segments (or accelerate joints into rotation) far removed from those to which it attaches (or spans). Furthermore, body inertia acts to filter the internal and external forces acting on the body such that the movement of the body segments can be a consequence long after they occur.

The current conceptual framework of sensorimotor control in human gait is at an even earlier stage of scientific development. One primary reason is concepts for sensorimotor control of motor tasks hardly exist in general, much less for human gait specifically. For example, some investigators advocate that the nervous system can construct internal models of the musculoskeletal system from which sensorimotor control can emerge; others that the nervous system acts to excite muscles to establish limb mechanical impedance to ensure limb and body stability; and others a combination of these two principles. Perhaps the concept most relevant to human gait, one would think, is pattern-generator neural circuits (presumably in the spinal cord). Though this concept is under intense development in non-primate vertebrates, its usefulness to delineating concepts of sensorimotor control at the muscle level in humans during gait will remain low probably into the distant future.

Gait measurement techniques now provide volumes of kinematic data (e.g., position of the segments), kinetic data (e.g., ground reaction forces), and neural output data (e.g., EMGs). This information in the hands of experts (e.g., clinicians or engineers in a clinical environment) can be an asset to diagnosis, treatment, and assessment. However, the effective utilization of this data is based on hands on experience. The clinician or engineer is, in effect, an "expert system" and, as such, the level of expertise is significantly influenced by the number of observations (i.e., the clinical experience).

Current gait analysis techniques have evolved to "massage" the gait data (e.g., to produce net joint movement and net joint power); and the technique of "massaging" has indeed progressed to an advanced state. However, these inverse dynamics methods have severe limitations in their ability to elucidate muscle coordination concepts because, fundamentally, they are not muscle based.

What is needed for basic concepts of muscle coordination to evolve? I submit that a muscle-based computer model and how the musculoskeletal system interacts with the environment (e.g., ground) during gait must become an integral part of the R&D effort. Computer models are the cornerstones to the understanding of the control and the dynamics of any large scale system, such as aircraft control and satellite control system design. The complexity of the computer model used to describe the musculoskeletal system depends, of course, on the specific intent (clinical objective) of the R&D project and our conceptual understanding of muscle coordination of gait. What makes a model critical to the advancement of a scientific discipline is that the assumptions an investigator makes must be explicitly defined. Such precise clarification of the assumptions provides others with the ability to criticize the conceptual framework being assumed. Computer simulations of gait, the outcome from these forward dynamic models, provide data to refute or support these criticisms. Thus, systematic scientific progress can be made regarding our understanding of muscle coordination of gait.

The generation of computer simulations of gait from musculoskeletal models is, however, challenging because determining the excitation pattern of the many muscles involved in gait is non-trivial. Nevertheless, computer algorithms exist which can find the muscle coordination pattern most consistent with the kinematic, kinetic, and EMG measurements, and /or other assumption. In this scenario, we have created an "*in vitro* tester," whereby it is conceivable that simulations could be created for various proposed surgical and rehabilitation musculoskeletal interventions, and potential functional (gait) outcomes predicted. Futuristically, such a testbed could be created for each patient from a generic model. Thus, the computer simulation testbed for gait would serve as a tool to design and plan surgical and rehabilitation strategies for individuals with not only similar musculoskeletal pathologies but unique ones as well.

Of course, in reality, it is the nervous system with its biologically-based sensorimotor-control algorithm that dictates the muscle coordination pattern, not the artificial computer algorithm, regardless how closely the simulation data generated from the computer algorithm agrees with the measurements. Unfortunately, computer models of the sensorimotor control system are really in their infancy and highly speculative. It will probably require quite ingenious experiments on gait or other locomotor tasks to postulate a credible 1st-generation structure for sensorimotor control. Sensorimotor control data is incredibly sparse. Nevertheless, computer models of the musculoskeletal system could be combined with models of sensorimotor control to generate gait simulations. These neuro-musculo-skeletal computer models would then serve as testbeds for studying gait disturbances whose etiology could be not only musculoskeletal but neural as well.

2.4.3 TOPIC III Factors which prevent the people with locomotion disabilities from accessing gait analysis.

Gait Analysis in Cerebral Palsy: Why isn't it Routinely Used?

James R. Gage, M.D.

I. Gait Analysis

A. What is it ?

1. Gait analysis could be considered to be a continuum ranging from simple observation of gait at one extreme in which no technological aids are used to the use of complicated and expensive equipment at the other.

2. Components of a typical modern system include:

a. video system

b. motion measurement system

c. dynamic electromyography

d. one or more force plates

B. How did it begin ?

1. Edward Muybridge

a. could be considered the father of motion analysis as well as the movie industry.

b. over the period of 1872-1888, Muybridge managed to obtain clear, still pictures of Leland Stanford's horse accident trotting. When projected rapidly through a device known as a zoopraxiscope, an observer would get the impression of seeing the animal in motion.

II. Is Gait Analysis Useful?

A. Some of the questions required to answer this are:

1. Is there a problem with traditional methods of treatment ?

2. What does motion analysis offer us that we don't already have ?

3. Does gait analysis necessitate a large, highly trained staff ?

4. Is it cost effective ?

B. Is there a problem with traditional methods of treatment ?

1. Without objective analysis of outcome, how can you tell ? It is my personal opinion that the "state of the art" in the treatment of cerebral palsy consists of:

a. poor understanding of the pathophysiology of the condition

b. a lack of knowledge of the principles of normal gait

c. little or no understanding of pathological gait

d. "surgery by eye" as opposed to objective measurement parameters

e. a tendency to do staged corrections of one muscle group at a time followed by long periods of immobilization after each intervention

2. After becoming Director of the C.P. Service at NCH, I turned to gait analysis because of:

a. poor patient outcomes
b. inconsistent results of treatment
c. dissatisfaction on the part of parents, therapists, and patients

3. As a result of this approach, the childhood of a patient with cerebral palsy becomes a series of surgeries and recoveries, and if one looks at critical parameters of evaluation such as oxygen consumption, most of these children have not been helped by the interventions.

C. What does motion analysis offer us that we don't already have ?

1. Objective assessment and documentation of:
   a. pre-operative pathology
   b. post-operative outcome

2 It really allows practical application of the scientific method which is:
   a. the accumulation of facts
   b. organization of these facts into principles or laws
   c. postulation of hypotheses to account for the facts and laws

3. Before we had this tool to assist us with treatment of cerebral palsy, we would start with a spastic child who walked abnormally and end with a spastic child who walked differently, but it was difficult to tell exactly what surgery had accomplished.

4. Accurate critique of surgical outcome prevents the perpetuation of errors into the future.

5. Results of treatment become much more predictable.

D. Does gait analysis necessitate a large, highly trained staff?

1. Current commercial systems run on a desktop computer.
2. Commercial software is friendly; usually in a “windows” or Macintosh format.
3. A minimum clinical laboratory staff would probably consist of a computer technician, physical therapist, secretary, and a physician who is able to interpret the data.

E. Is it cost effective ?

1. In our laboratory gait analysis which includes video, kinematics, kinetics, EMG, and oxygen consumption and cost runs about $2000.
   a. this is roughly the cost of a CT or MRI scan
   b. it enables multiple lower extremity procedures with predictable outcomes
   c. what is the cost of a treatment error in a child with a 60 to 70 year life expectancy?

III. If gait analysis is so useful, why isn't it in wide use?

A. Physician attitudes

1. Training generally does not include gait analysis and/or engineering mechanics.

a. absence of engineering in training means fear or reluctance to use engineering principles in practice

2. Orthopaedic residency is basically an apprenticeship and gait is not understood or taught by the student's preceptor.

a. earlier generations of orthopaedist's who worked with polio actually had a better understanding of gait than those of the present day

b. the Orthopaedic In-Training Examination generally includes traditional questions on cerebral palsy and few if any questions on cerebral palsy gait and/or gait analysis

3. The necessity of laying down previous practice and accepting a different way is difficult since the implicit implication is that previous practice was incorrect.

4. This is a technology with a price in terms of utilization.

a. MRI's and CT scans are useful without any background knowledge beyond anatomy

b. a great deal of time and study is required to master the principles of normal and pathological gait and gait analysis

B. The laboratory itself

1. Although the cost of gait analysis has come down, the price of a reasonably equipped modern laboratory is still about $250,000.

2. A gait analysis laboratory requires a lot of space.

3. Funding must be found for at least three full-time employees.

4. All of the successful clinical laboratories of which I am aware have an associated physician to provide an interpretation of the data.

5. There is a lack of standardization among existing laboratories which acts to confuse physicians and payers.

C. Refusal of third party payers to recognize value and/or assume cost

1. Centers of excellence have difficulty because:

a. the surgeon to patient ratio is high and hence surgeons are reluctant to refer away patients -- even those with conditions they don't understand

b. managed care programs usually make it very difficult to access to physicians who are "out of plan"

c. gatekeepers and capitation both act to ration or restrict treatment

2. Although most managed care systems talk of "quality and cost," to date the emphasis has been entirely on the latter.

3. As long as gait analysis is not commonly accepted medical practice, third party payers will continue to resist it.

a. in general, any new or non-traditional practice of medicine is labeled "experimental" and payment is denied.

4. Managed care seeks to minimize costs of expensive individuals and get them out of their network as soon as possible. Currently, there is no incentive to optimize the function of these individuals -- in fact the converse is present.

To summarize, in gait analysis we have a technology which can describe, quantify, and elucidate the mechanisms by which walking occurs; reveal what has happened when walking is disrupted, and in some cases indicate which treatments are most likely to restore function to an optimal level. The technology has evolved to the point where it is reliable, easy to use and, compared to ten years ago, relatively cheap, and yet physicians, hospitals and payers are all resisting its use.

IV. Remedies

A. If gait analysis is to come into widespread use we need to:

1. Enlarge the scope of gait analysis, particularly into elite performance where it will be readily embraced by both the athletes and the public.

2. See that individuals who treat these patients receive active instruction in gait and gait related topics.

3. Demand objective outcome studies in all papers relating to treatment of these individuals.

4. Overhaul payment system so that there is incentive in producing an optimal outcome as opposed to minimizing treatment.

5. The benefits of gait analysis in the treatment of locomotor disabilities must be proven to colleagues, patients, and payers.

V. What is the Status of Gait Analysis Today?

A. Good commercial hardware & software systems are available at about 1/6 the price of the system built at Newington Children's Hospital in 1980.

B. Outcome studies are beginning to be published.

C. Acceptance is growing for gait analysis in the treatment of neuromuscular conditions.

D. A new journal entitled *Gait & Posture* is now being published.

E. Motion analysis is beginning in prosthetics, sport's medicine, and other performance related activities.

F. A few final thoughts:

1. As stated earlier, before we had this tool we would start with a spastic child who walked abnormally and end with a spastic child who walked differently, but it was difficult to tell exactly what the surgery had accomplished. Now, however, we have a tool by which we can accurately critique our surgery.

2. The technology of gait analysis is moving rapidly, but physician attitudes need to change:

a. There is a wide spread perception among orthopaedic surgeons that clinical examination and observational gait analysis are adequate to determine treatment. I hope I have succeeded in proving to you that this is not the case.

3. If we as physicians and therapists wish to treat human gait problems of any type, we must be:

a. willing to commit the time and effort necessary to master the principles of normal and pathological gait. A. Bruce Gill said it best, "Study principles not methods; if one understands the principle he can devise his own methods."

b. familiar with the technology used to measure gait and the basic principles of biomechanics.

c. willing to participate as a member of a team which includes members from other disciplines such as engineering, kinesiology, and physical therapy.

4. Nothing in life can be consistently improved or optimized unless it can be subjected to objective analysis and its governing principles and/or mechanisms are well understood --- Cerebral Palsy is no exception!

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Factors which prevent the people with locomotor disabilities from accessing gait analysis

Edmund Y. S. Chao, Ph.D.

Routine access of gait analysis as a tool for clinical application has not been extended to patients without locomotor disabilities. It is, therefore, not surprising to find that such methodology is grossly overlooked on its value in studying individuals who have different degrees of locomotor disabilities. To review the factors which prevent patients from accessing gait analysis will be helpful to lay the background to discuss similar issues concerning people with locomotor disabilities. Cost, reliability, accuracy, and clinical relevance have been the four main factors preventing routine access to gait analysis in patients with locomotor problems. Additional research and development must be devoted to this field in order to overcome these barriers. Gait analysis is one of the earliest biomechanical techniques applied to both basic research and clinical application but many of the past efforts were devoted to measuring instruments and data capturing methodologies. Data analysis and establishment of a reliable database on both normal and patients with locomotor abnormalities have not received adequate attention and emphasis in the past. There is also a lack of appreciation of how complex bipedal locomotion actually is and how one may reach inappropriate conclusions based on very limited data. Additional barriers exist when such technology is being considered for individuals with locomotor disabilities. First, the definition of gait must be redefined by expanding its scope. Second, the outcome of such analysis should include locomotion efficiency, comfort, exercise and rehabilitation values, and prevention of secondary injuries. Improvement of assistive tools and equipment including locomotor robots must be part of such effort. Third, reliable and effective indices reflecting an overall rating of gait (or locomotor) performance must be developed for easy reporting of analysis results and data documentation. Finally, gait should not be limited to the functional contributions of the lower limb alone. The trunk and upper extremity do play a significant role in the efficiency and the compensatory effect of human mobility. With a combined effort by the bioengineers, therapist, rehabilitation physicians, gait analysis will remain a mainstay in medical rehabilitation research and in the management of patients with locomotor disabilities.

2.5 Breakout session: Day 1

2.5.1 Goals

The goals of the first breakout session were to develop a comprehensive list of recommendation concepts under each category heading and assign recommendation development responsibility to individuals or teams. Specifically, participants were asked to first develop a comprehensive set of recommendation categories. Then potential recommendation topics (titles or themes) were generated and placed under appropriate categories. Finally, the session ended with teams selecting recommendation topics on which they will develop recommendations during the second breakout session.

The focus of each working group related to one of the following questions.

What needs to be done to:

Group 1) improve the use of gait analysis as a patient assessment tool?

Group 2) better the treatment planning and/or treatment implementation uses of gait analysis?

Group 3) increase the accessibility of gait analysis for people with locomotion disabilities?

2.5.2 Team decision-making process:

Co-chairs were instructed to implement a team decision making process. This process began with a silent individual generation of ideas. Next, participants were asked to present their ideas without discussion. During this phase, team members were encouraged to listen and take notes. Once all participant ideas were presented, an open discussion of individual ideas took place. Final decisions were then enacted.

2.5.3 Team Warm-up: Day 1

Co-chairs were instructed on importance of team warm-up activities. These activities were designed to prepare participants for the rigors of team work. Co-chairs were strongly encouraged to begin the first breakout session with the following warm-up activity:

Warm-up
Day 1

We make the assumption that you come to this meeting bearing a lot of distractions. Just as it is important to stretch muscles prior to exercise, we would like you to stretch your mind each day prior to your participation in this group. The following warm-up activity is designed to help you leave behind concerns and ease into the meeting, to gradually focus on the task of developing recommendations.

We would like you to introduce yourself to the other members of your table. Please address each of the following questions during your introduction.

1) What is your name?
2) Where do you work?
3) What did you want to be when you were a child?
4) What is your favorite weekend recreation?

2.5.4 Team Leader/Spokesperson Selection Process

Workshop coordinators wished to create an atmosphere in which participant ideas were assumed to have equal weight. To facilitate this idea, a lottery technique was used to select team spokespersons. These individuals were required to periodically provide oral reports to the working group regarding the status of recommendation development. The process by which these individuals were selected is described in the following five steps.

1) All participants write a number between 1 and 100 on a piece of paper
2) Pass paper to the person on your right
3) Chairs call out one number between 1 and 100
4) Person holding closest number is elected
5) For ties, the process was quickly repeated

2.5.5 Breakout session tasks: Day 1

The primary goal of breakout session one was to prepare participants for the task of recommendation development. During this session participants were systematically lead through the following list of activities.

1) Review and discuss the sample recommendation.
    a) Silent review (5 min.)
    b) Team discussion
    c) Question and answer period at the working group level

2) Generate a list of recommendation categories.
    a) Within teams, start with silent generation of ideas (5-10 minutes)
    b) Each team creates a written list of ideas (without discussion)
    c) Within teams, discuss and clarify team list of ideas
    d) Team spokesperson reports list to co-chairs
    e) Co-chairs develop and post a master list of recommendation categories.

Display each category heading at the top of a large sheet of paper.

3) Generate a list of potential recommendation titles within each category.
   a) Start with silent generation of ideas (5-10 minutes)
   b) Each team creates a list of ideas (without discussion)
   c) Within teams, discuss and clarify team list of ideas
   e) Team spokesperson reports draft titles to chairs without discussion
   f) Chairs write each title and team (table) number under the category heading
   g) Working group, discuss like titles and combine when appropriate

4) Assign individual titles and associated categories to teams.
   a) Redistribution of team participation at this time is acceptable
   b) Select new team leaders/spokespersons if necessary

5) Teams create strategy for developing draft recommendations.

2.6 Breakout session: Day 2

The goal of the second breakout session was to develop a set of completed recommendations. Participants were given the entire day to accomplish this task. Following a brief warm-up activity, participants began the arduous task of recommendation development. During this session, team spokespersons were periodically asked to provide verbal reports to the working group. When deemed necessary by participants, adjustments to work assignments were implemented. While co-chairs circulated amongst working groups, conference coordinators maintained a vigil over the three working groups, periodically facilitating the process of recommendation development.

2.6.1 Warm-up activity Day 2

Warm-up
day 2

Today's warm-up is called Superlatives. Take a minute to study the composition of the group and silently decide on a superlative adjective (youngest, tallest, baldest...) that describes yourself in contrast to the other members of group. When everyone has selected their superlative go around the table sharing adjectives and testing the accuracy of your perceptions.

2.7 Recommendation Development Materials

Workshop participants were provided the following reference materials, including the sample recommendation, to assist them during the recommendation development process.

Working Group Report Guidelines

The completed conference report will contain recommendations created during the meeting. It is anticipated that each of these conference recommendations will contain elements of attendees' initial position statements and new material introduced during the conference. In order to facilitate the development of conference recommendations, participants are strongly encouraged to further research topics and prepare written materials in advance of the conference using the following format and draft recommendation as guides.

Recommendation Title: (Developed by working group)

Recommendation Code: (Assigned by Co-chairs)

Category: (Assigned by working group)

All recommendations will be categorized according to the general nature of the specific actions being recommended. The following list of categories can be used as a guide: (research, education, training, standardization, policy, technological development, other).

Recommendation

Background

This section should contain the background/rationale for the issue/problem/question for which research, development, or policy/program changes are being recommended. (Typically, this will consist of one or more affirmative statements indicating what has been achieved and what remains to be achieved in a given area.)

Objectives

List the specific objectives that should be pursued. (These statements should characterize the desired resolution of the issue/problem/question described in the background section.)

Recommended Actions

This section should contain the specific recommended action(s) to achieve the objective(s) specified in the objectives section. (These are the research questions, developments, or policy/program actions that should be pursued to achieve the objective(s) specified above.)

2.7.1 Sample Recommendation

(EXAMPLE RECOMMENDATION)

Recommendation Title: Training Fellowships for Physical Therapists

Recommendation Code: Z1

Category: Training

Recommendation

Background

A major barrier to the clinical implementation of gait analysis technologies in rehabilitation settings, and therefore access to these technologies, is the excessive resources required to purchase, maintain, and implement a modern motion analysis laboratory. The initial cost of equipment and space allocation are important contributing factors which require a significant initial institutional commitment. However, these initial investments pale in comparison to the annual salary and benefit expenditures required to maintain laboratory staff. Historically, the operating complexity and immaturity of gait analysis technologies have demanded gait laboratory staffing trends to include a senior technical director (often a Ph.D.), technical assistance (engineering staff), and a clinical coordinator who is responsible for patient testing and report generation (typically a physical therapist or kinesiologist). Recent advancements in motion analysis technologies provide a level of automation and sophistication such that a clinician who obtains sufficient training and experience with gait analysis technologies is capable of independently executing the wide range of tasks associated with modern gait analysis.

Objectives

Decrease the annual cost of supporting a clinical gait analysis laboratory by replacing the present day multi-staff model with a single staff model consisting of a hybrid cross-trained licensed physical therapist.

Recommended Actions

Develop fellowship training programs at centers of excellence that will provide licensed physical therapists extensive training and experience in modern gait analysis technologies and the integration of these technologies into the patient care setting.

2.8 Priority Scoring of Recommendations

The recommendation scoring session was preceded by a recommendation review session. While participants received the recommendations the evening prior to the scoring session, it was felt that a group review session would improve participant focus. During the review session, co-chairs summarized the list of recommendations that were generated within their respective working groups. An attempt was made to minimize discussion that would result in the development of participant interpretations that extended beyond recommendation text. The recommendation priority ranking process occurred in a group setting. Participants were instructed to use the full range of scores provided by the priority scoring system and were lead through the scoring process by a workshop coordinator. Participants were provided ample time to reflect on each recommendation prior to the recording of their score. Score sheets were collected prior to closing statements from the conference coordinators and participant dismissal. The following recommendation scoring system was used in conjunction with scoring sheet depicted in the following section.

100-200	Highest Priority
200-300	Moderate Priority
300-400	Average Priority
400-500	Low Priority
500-600	Lowest Priority

2.8.1 Sample Scoring Sheet

RECOMMENDATION SCORING SHEET

Circle Your Working Group Number I II III

When instructed to do so, please score each of the following recommendations using the NIH scoring system. All recommendations must receive a numerical score.

100-200 Highest Priority
200-300 Moderate Priority
300-400 Average Priority
400-500 Low Priority
500-600 Lowest Priority

#	Code	Recommendation Title	Score
1	A1	Gait Assessment and Clinical Decision Making	
2	A2	Gait Assessment and Functional Outcomes	
3	A3	Is Gait Analysis Efficacious in Improving Treatment Outcomes?	
4	A4	Accuracy, Precision and Validity of Movement Analysis Techniques	
5	A5	Evaluation of Clinical Interventions Using Functional Movement Analysis and…	
6	A6	Development of Standards for Management of Clinical Movement Analysis Data	
7	A7	Development of Timely and Objective Methods of Acquisition, Reduction and…	
8	A8	Development of a System Network for Sharing Movement Analysis Data Files	
9	A9	Education and Training of Personnel Involved in Gait Analysis	
10	A10	Determinants of Gait Related Pathology	
11	A11	Development of Models to Study the Relationship Between the Observed…	
12	A12	The Scope of Movement Analysis	
13	B1	Expand the Clinical Application of Gait Analysis	
14	B2	Gait Analysis as a Cost Effective Patient Management Tool	
15	B3	Use of Gait Analysis Technology as Treatment	
16	B4	Clinical Motion Analysis Databank with Patient Profiles	
17	B5	Standards for Reporting the Results of Clinical Gait Analysis	
18	B6	Collaboration via Telecommunications / Telemedicine	
19	B7	Improved Sensors of Neuromusculoskeletal Activity in Gait Analysis	
20	B8	Automated Protocol for Determining Joint Centers	
21	B9	Identify the Relationship Between Impairments, Functional Gait Limitations, and…	
22	B10	Toward Routine Utilization of Gait Analysis	
23	B11	Educate Clinicians in the use of Gait Analysis in Treatment Planning and…	
24	B12	Effectiveness of Gait Analysis	
25	C1	Advance Research Evidence for the Clinical Utility of Movement Analysis Across…	
26	C2	Scope and Availability of Gait Analysis Facilities	
27	C3	Establish Comprehensive Gait Analysis (GA) as a Standard of Care in…	
28	C4	Role of Three-Dimensional Computerized Gait Analysis in Treatment…	
29	C5	Time/Distance Analysis for use in Group/Multicenter Outcome Studies	
30	C6	Define the Components of Gait Analysis	
31	C7	The Development of Interactive Software to Assist Professionals in the…	
32	C8	Standardization of Gait Analysis	
33	C9	Accreditation of Diagnostic Clinical Gait Laboratories	
34	C10	Medical Education Models for Health Care Professionals	
35	C11	Consumer and Patient Education	
36	C12	Universal Access to Gait Analysis Services	
37	C13	The Development of Information Resources Which Will Help New Gait…	

2.9 Workshop Evaluation

This Workshop was an unusual design since the purpose was to develop, over a relatively short period of time, an extensive set of prioritized recommendations for future directions in gait analysis. This was the first opportunity to implement this workshop model. Therefore, a high evaluation participation rate was desired. To accomplish this goal, workshop evaluation forms were attached as a face sheet to the list of recommendations that was distributed the evening prior to the recommendation review and priority scoring sessions. On the final morning of the Workshop, a completed evaluation form served as the ticket with which participants could obtain a recommendation scoring form. Participants, working group chairpersons and observers were allowed to evaluate the Workshop.

2.9.1 Workshop Evaluation Form

Participant Evaluation for
Gait Analysis in Rehabilitation Medicine
September 26-28, 1996

1. Usefulness of the Meeting (and topics discussed):
   ___ Extremely useful
   ___ Very useful
   ___ Somewhat useful
   ___ Not useful

2. Organization and structure of the Meeting:
   ___ Excellent
   ___ Good
   ___ Average
   ___ Poor

3. Presentation of materials, (including handouts, slides, etc.):
   ___ Excellent
   ___ Good
   ___ Average
   ___ Poor

4. What was the best part of the meeting for you?

5. What was the weakest part of the meeting?

6. What improvements would you make if any?

7. Do you have any specific preferences for future Meeting topics?

8. Comments:

Please fill this out and return for a score sheet in the morning

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.

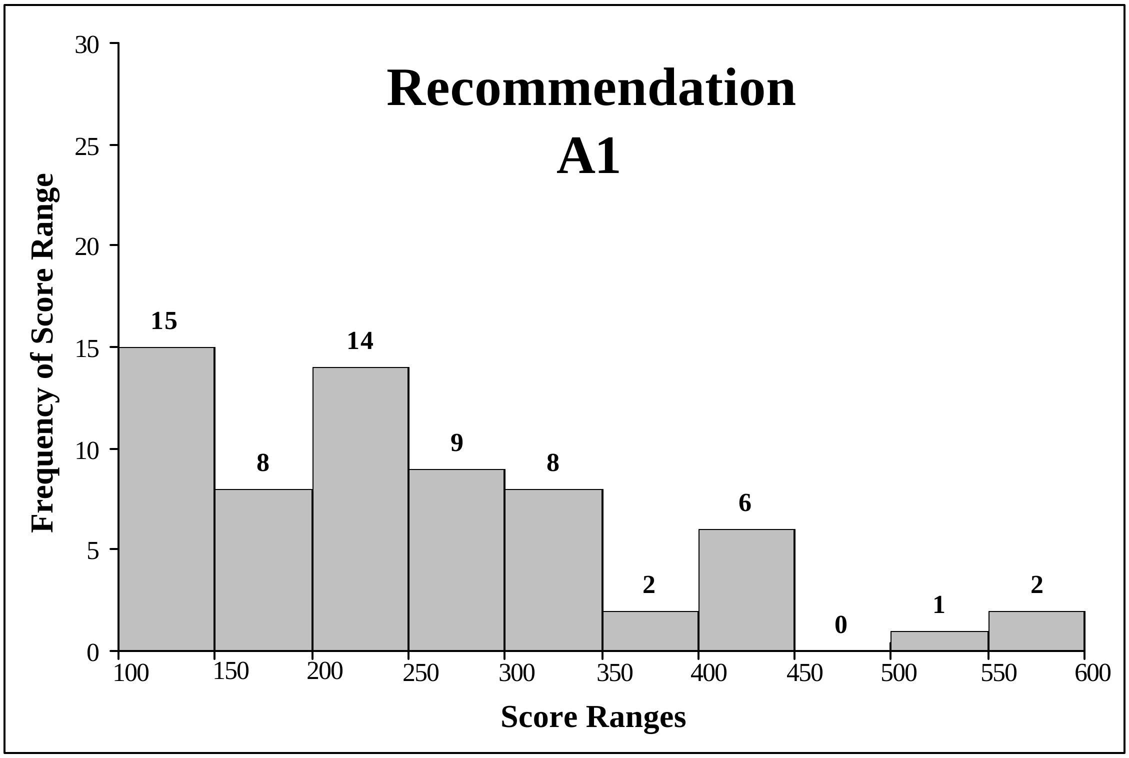
The differences between the earliest gait workshop and the most recent one at Crystal City, Virginia were very great. In the first place the number of gait laboratories in the United States, Canada, and Great Britain has at least tripled. The three methods presented for collecting and analyzing kinematic 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.

Appendix C:

Distribution of Scores for Each Recommendation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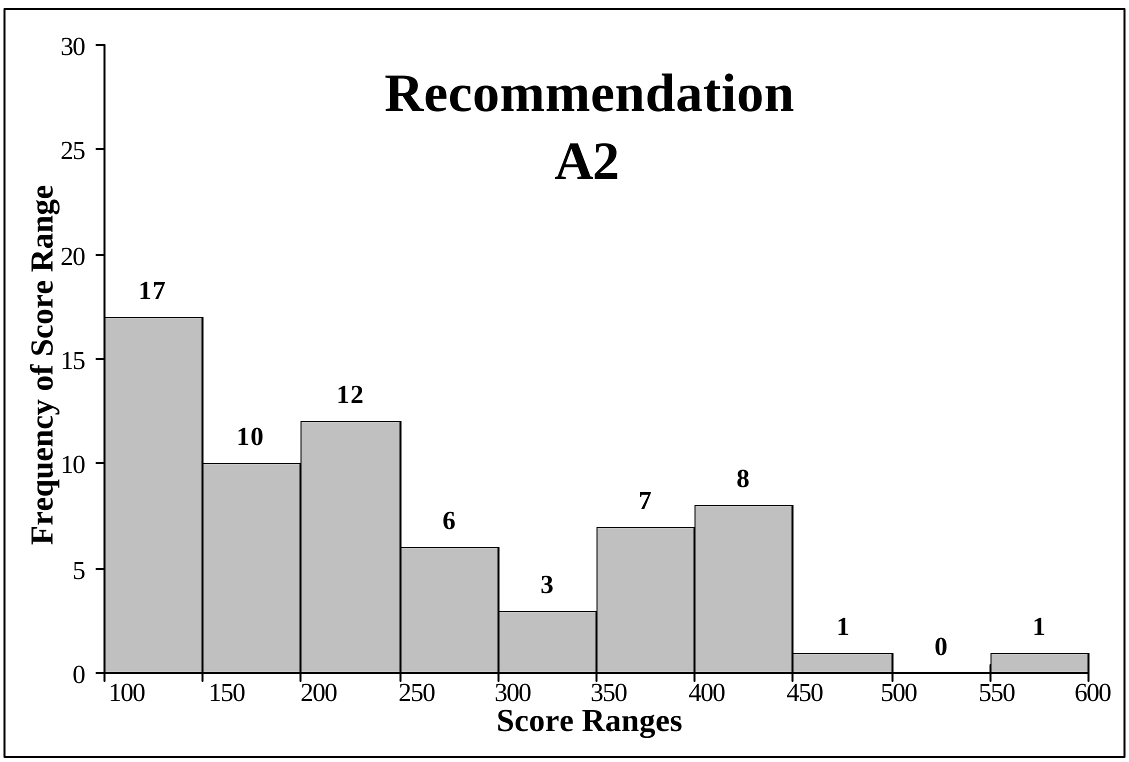
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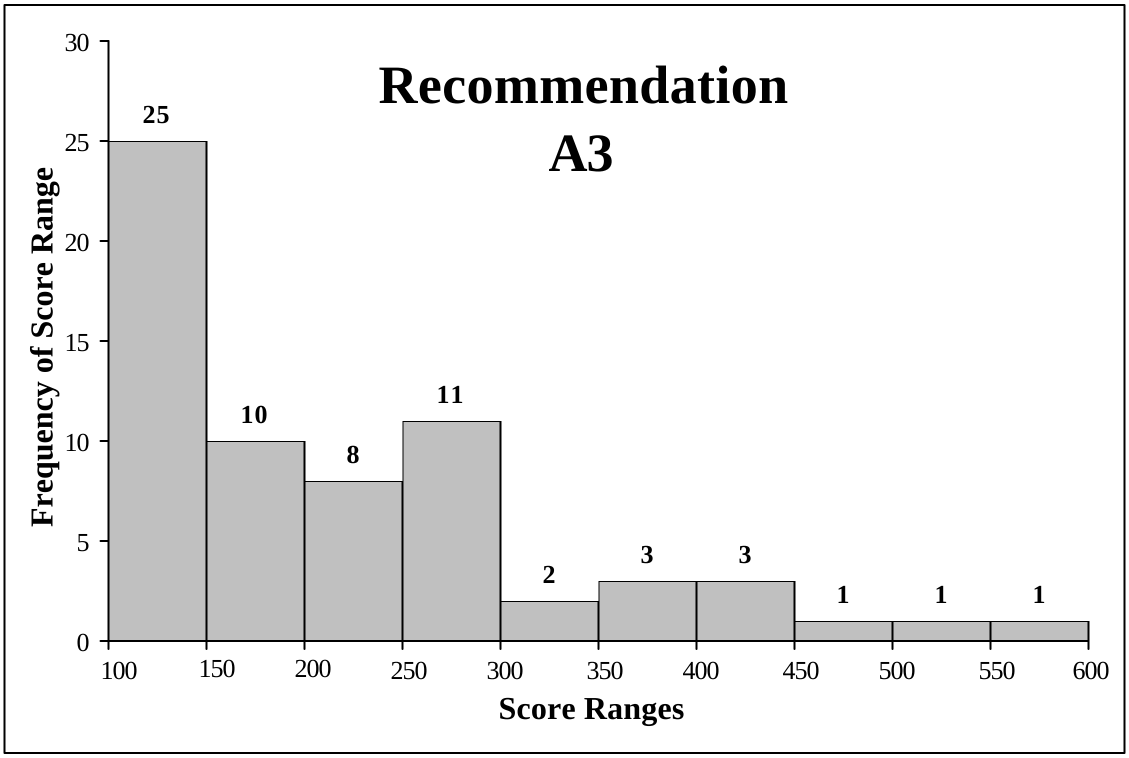
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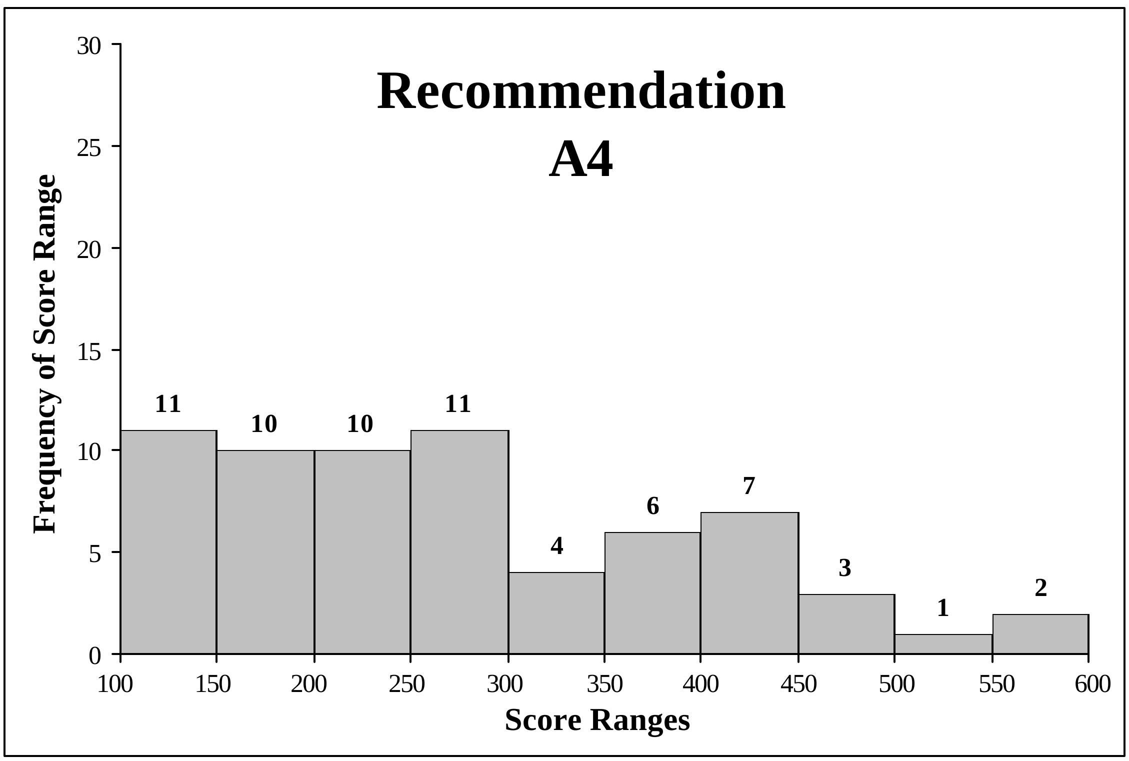
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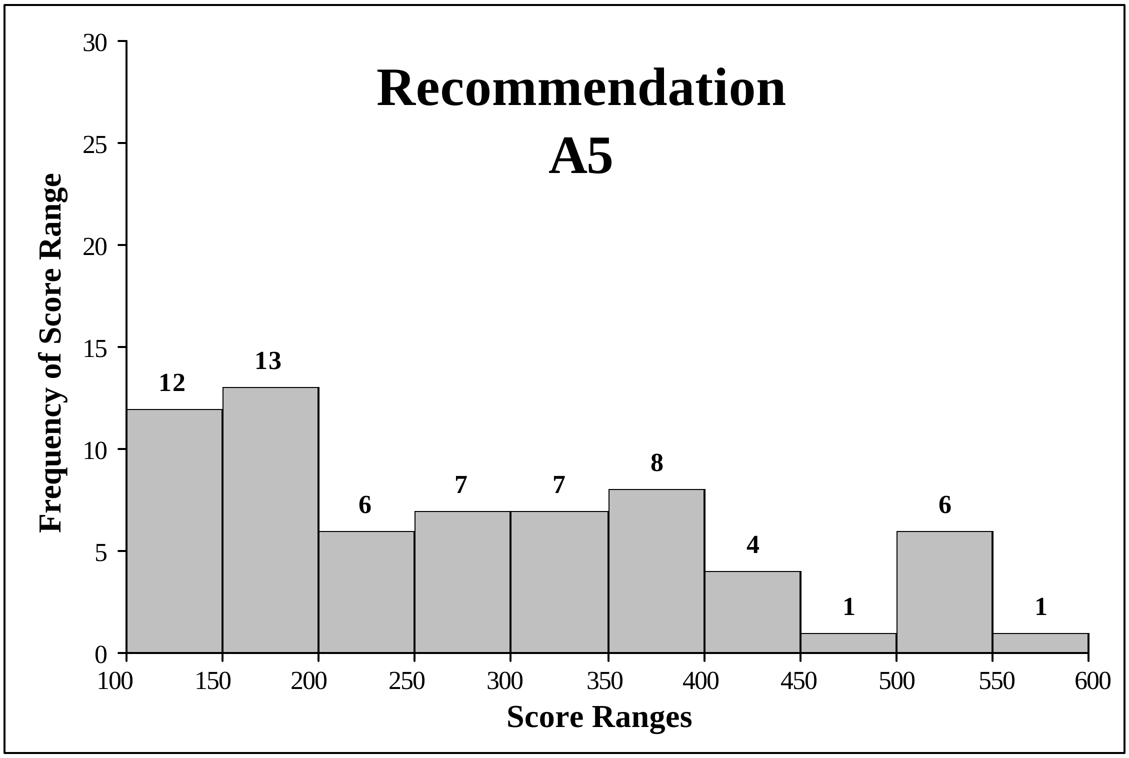
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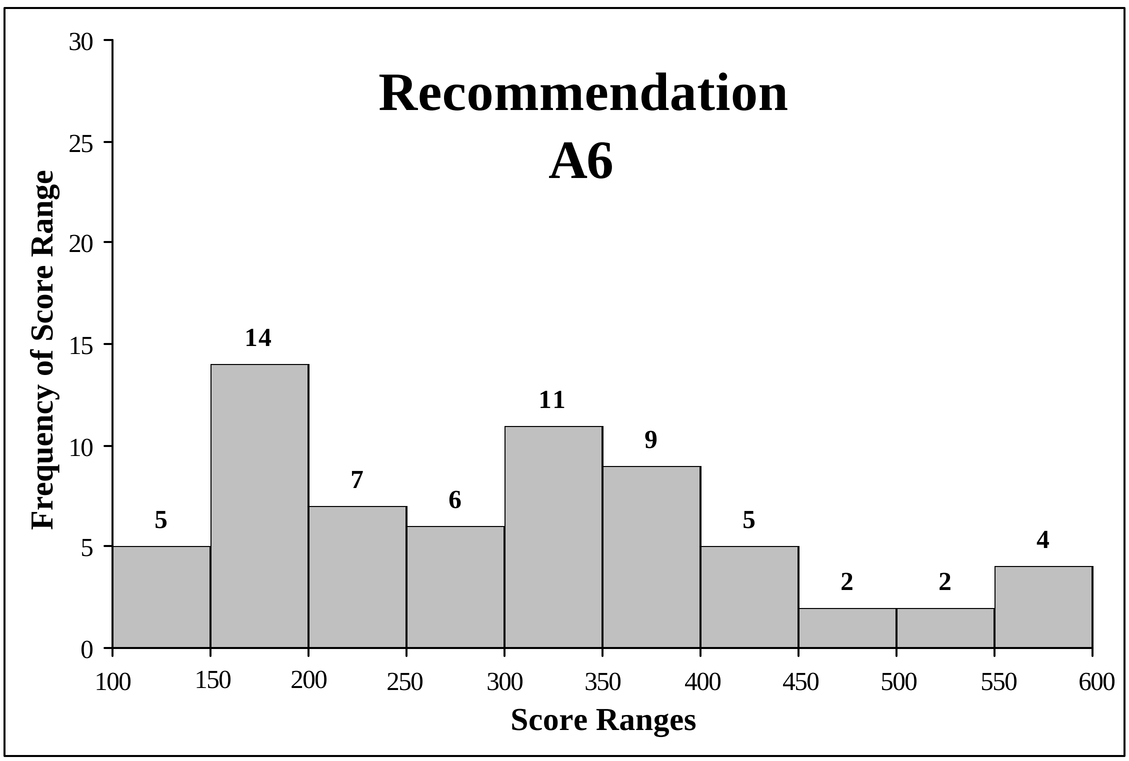
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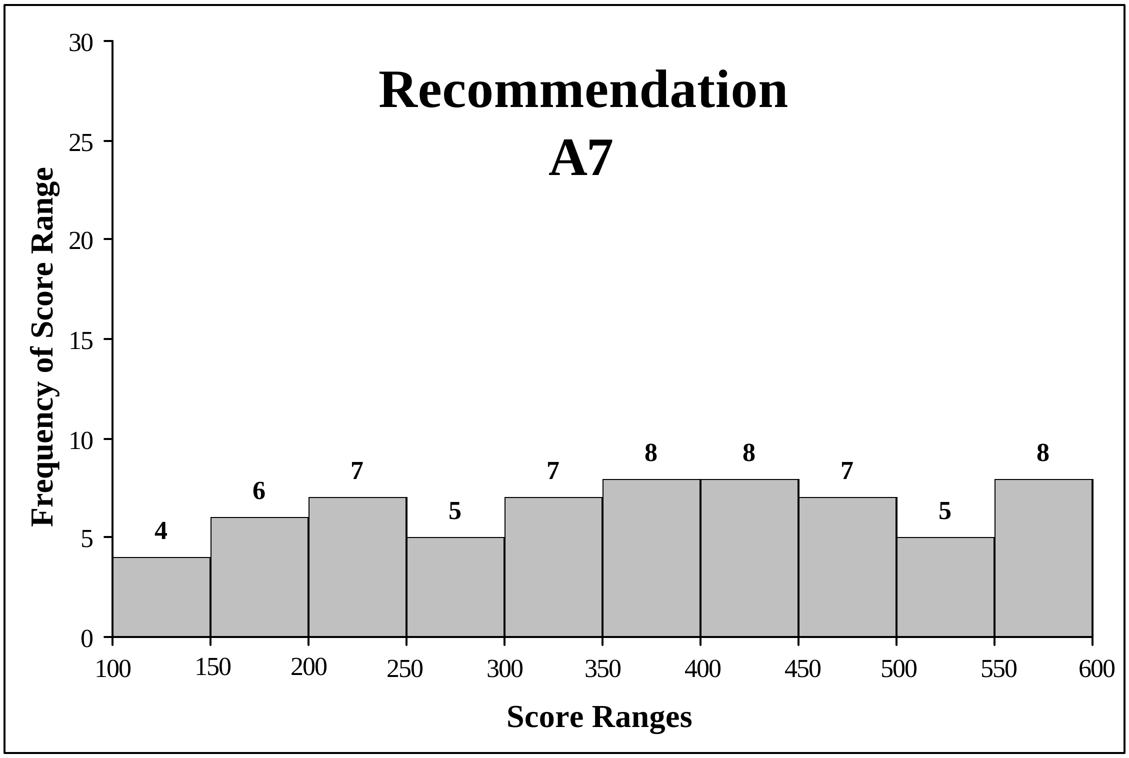
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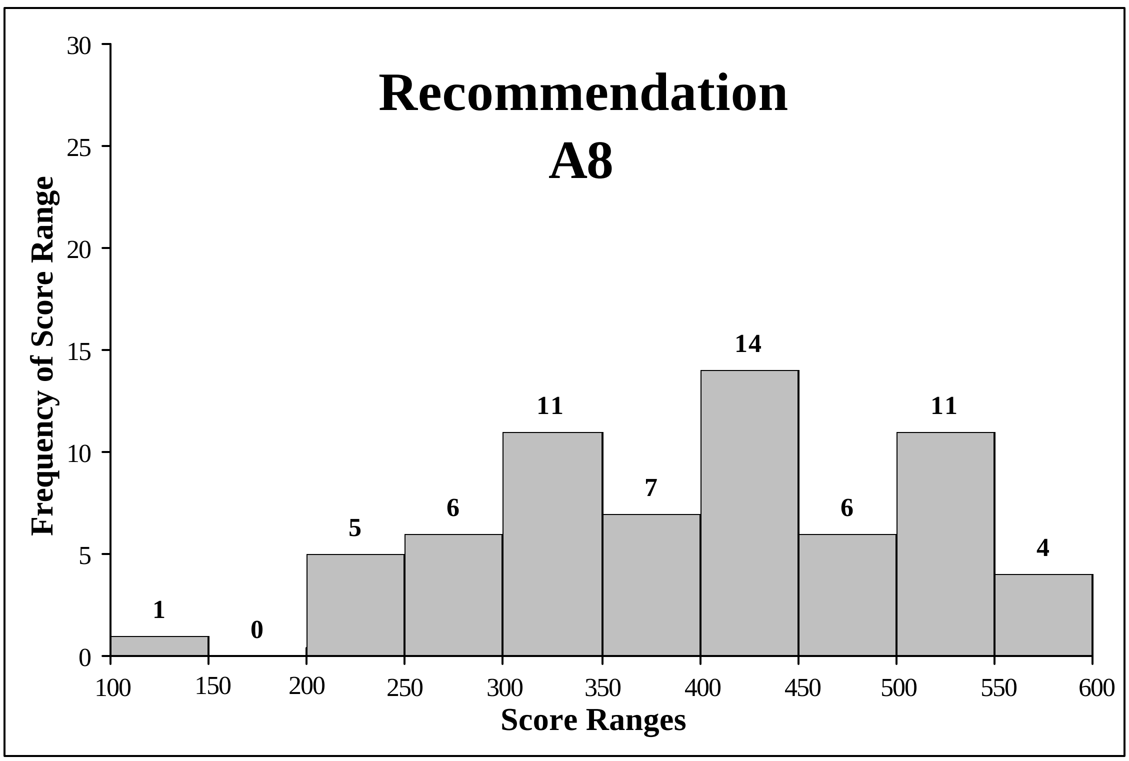
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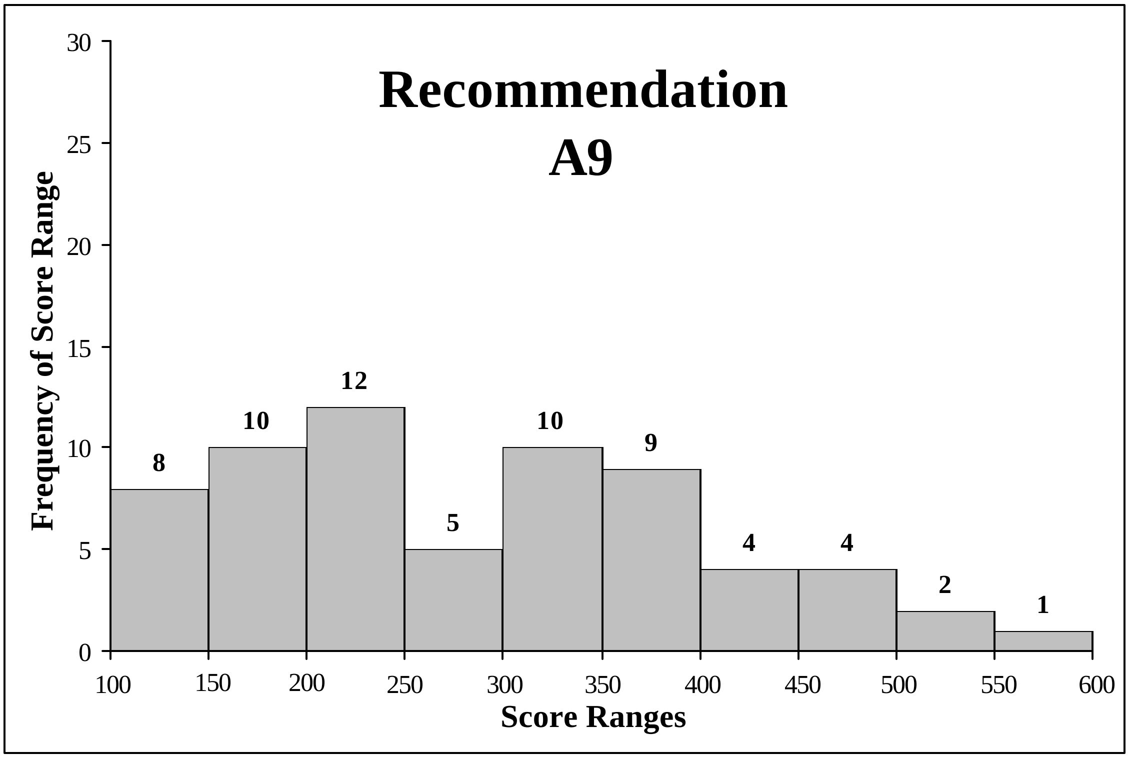
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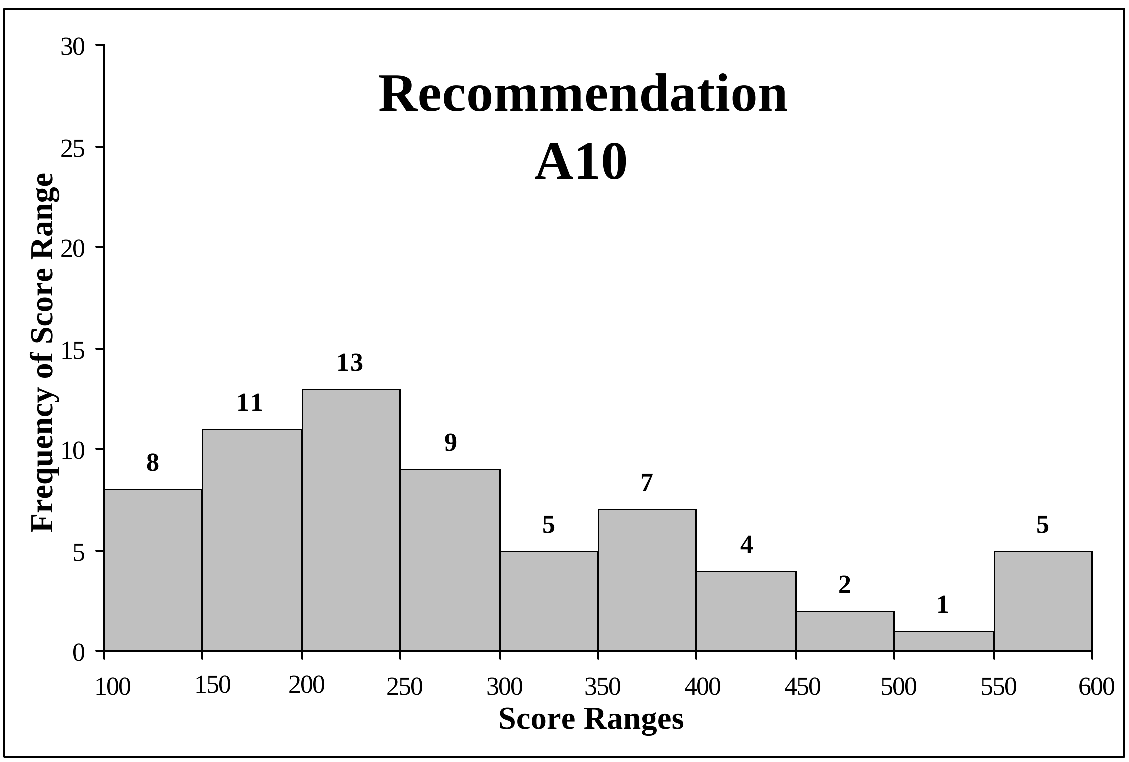
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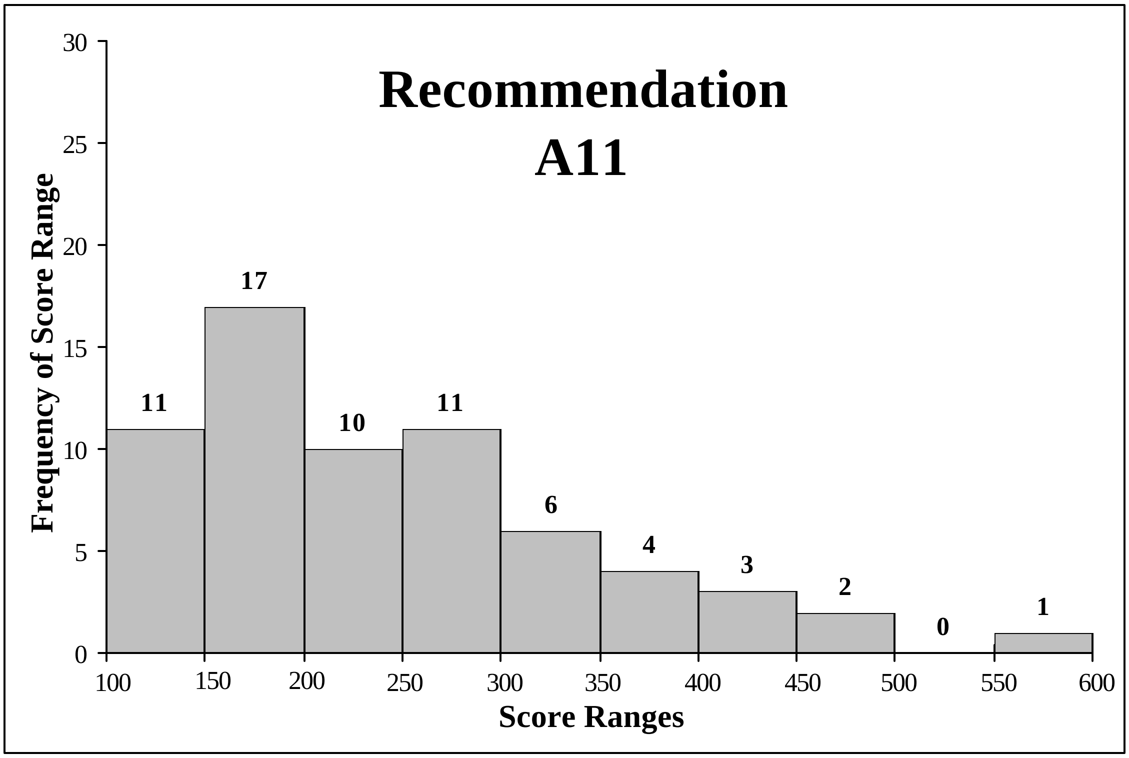
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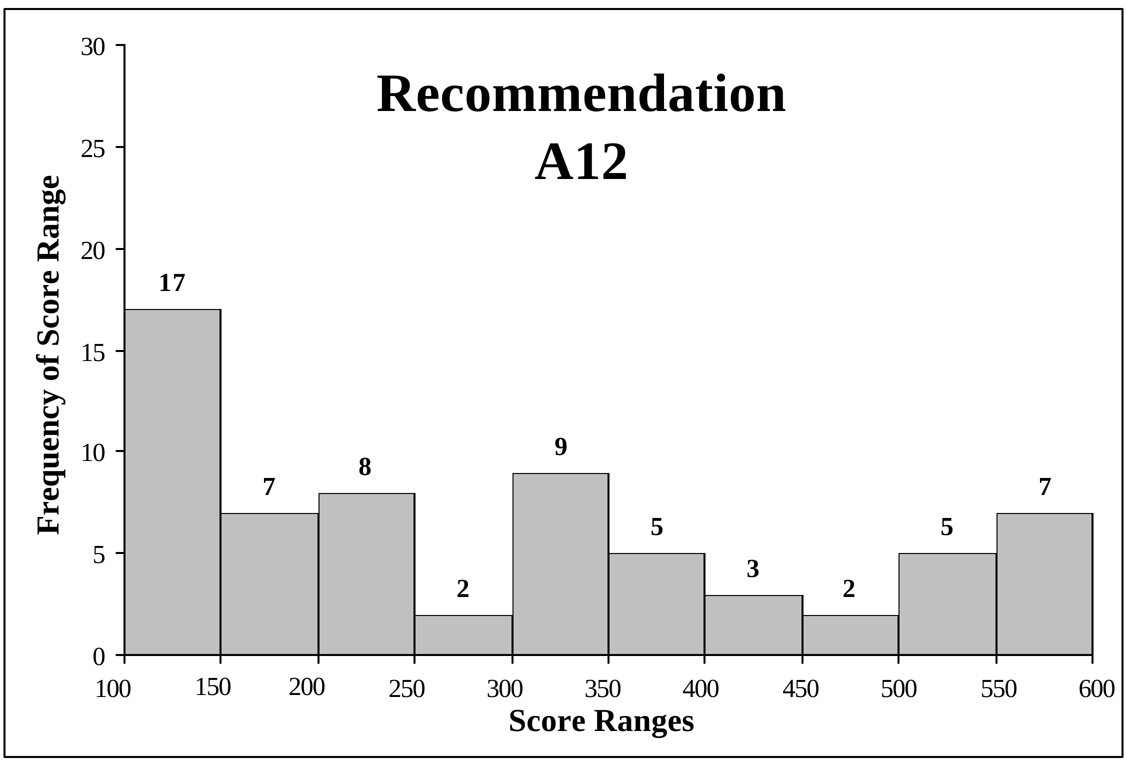
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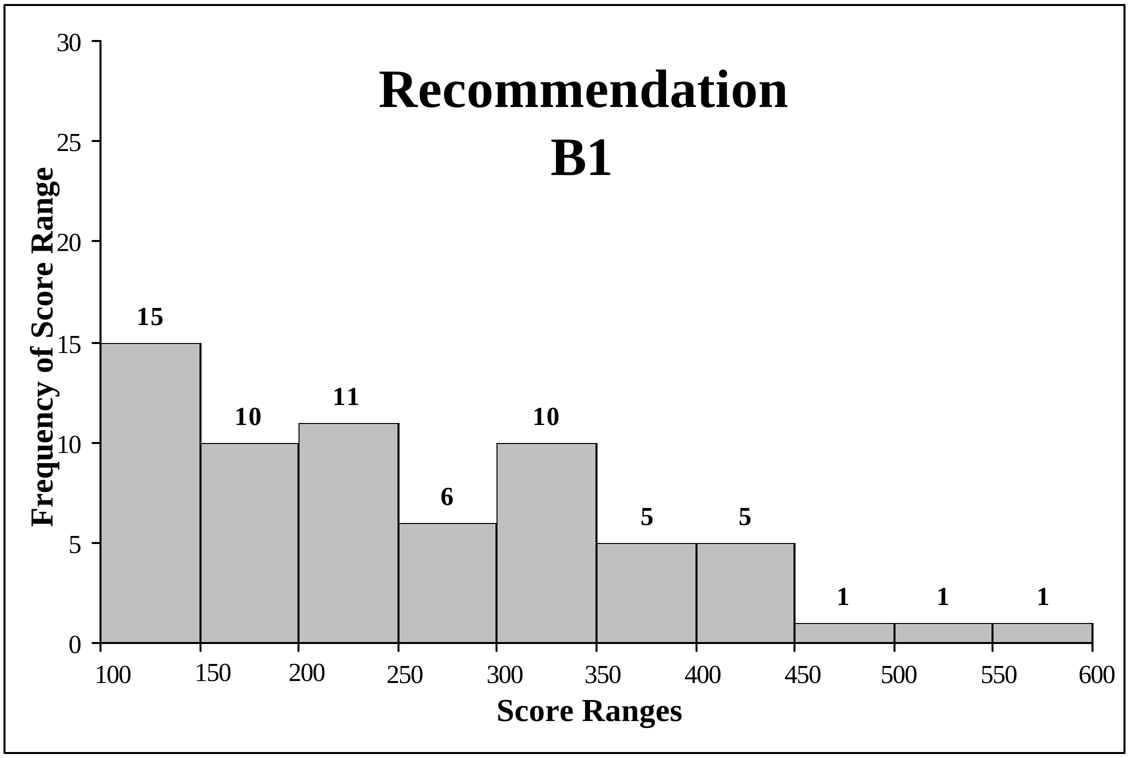
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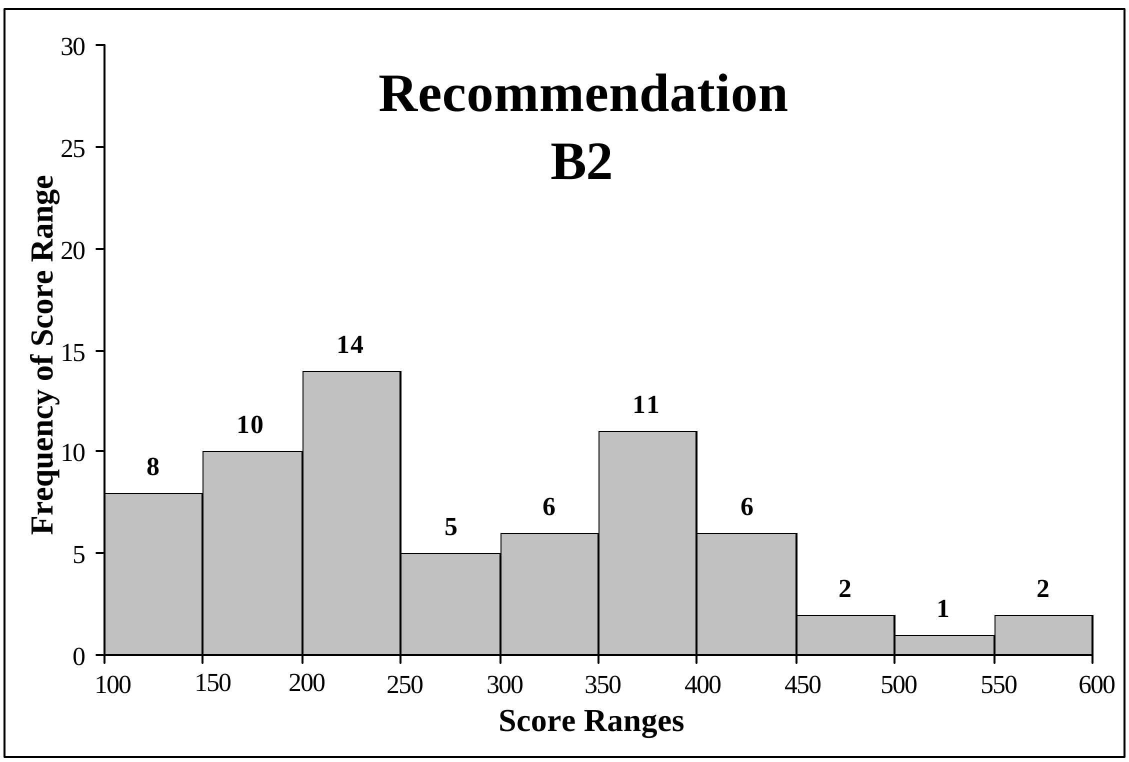
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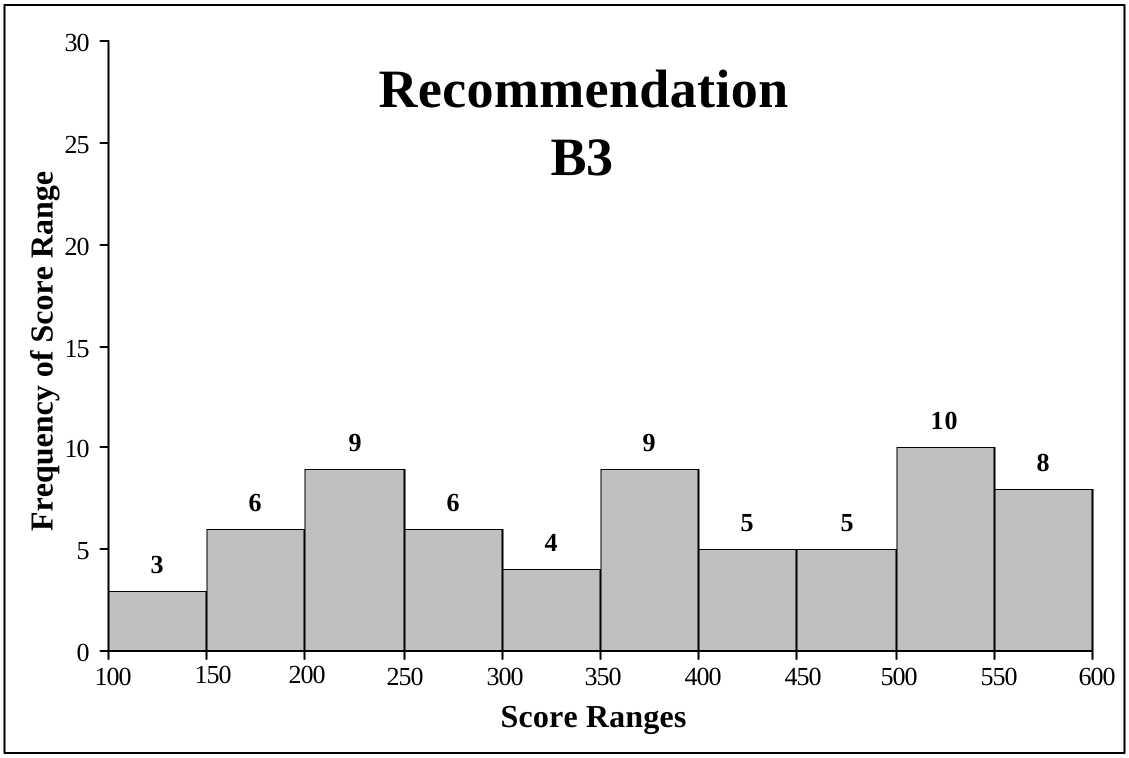
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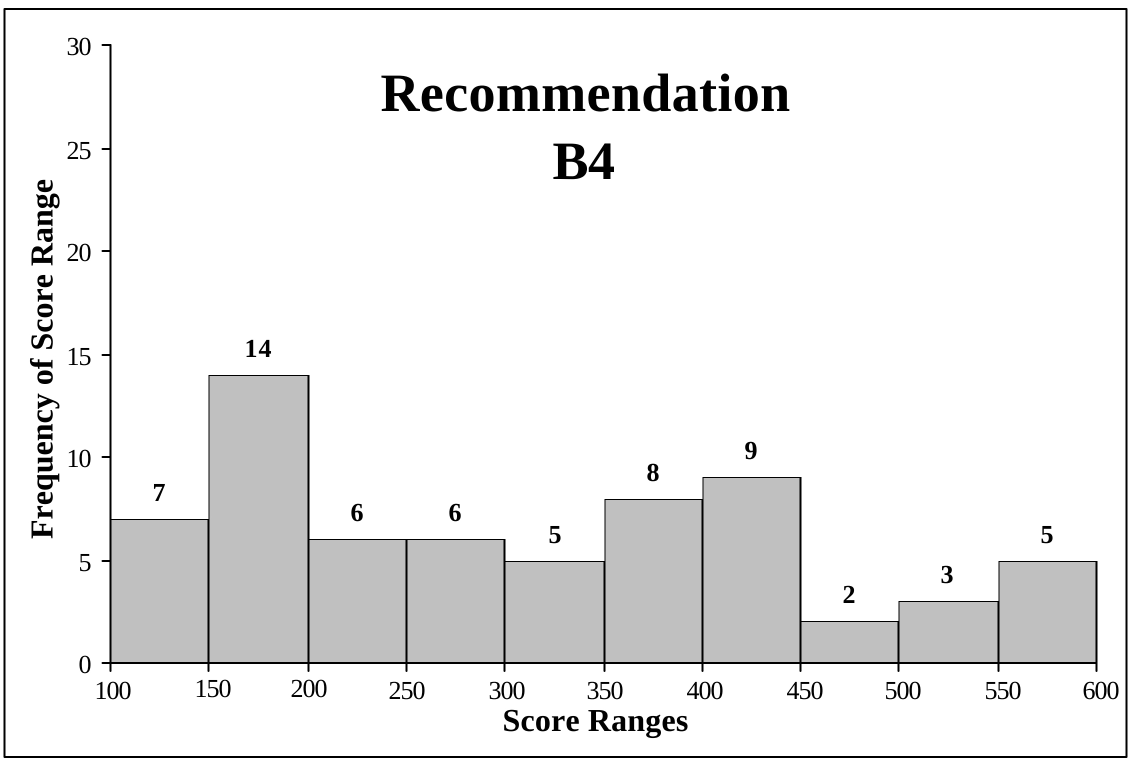
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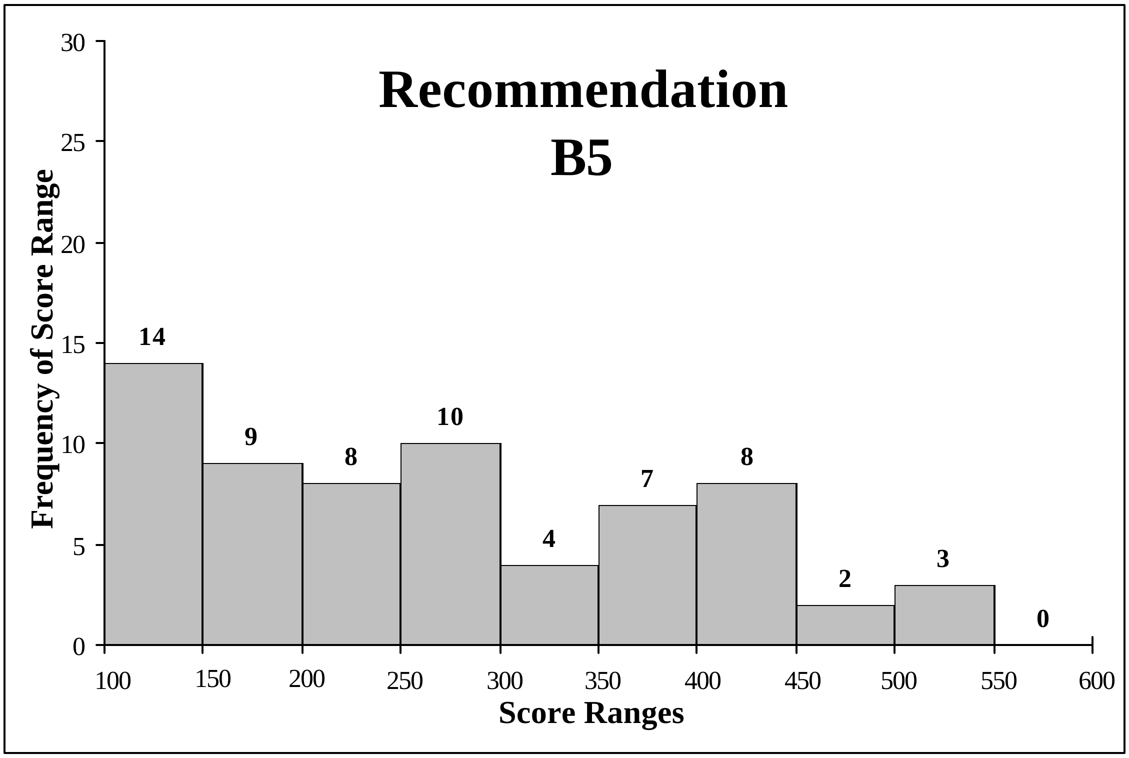
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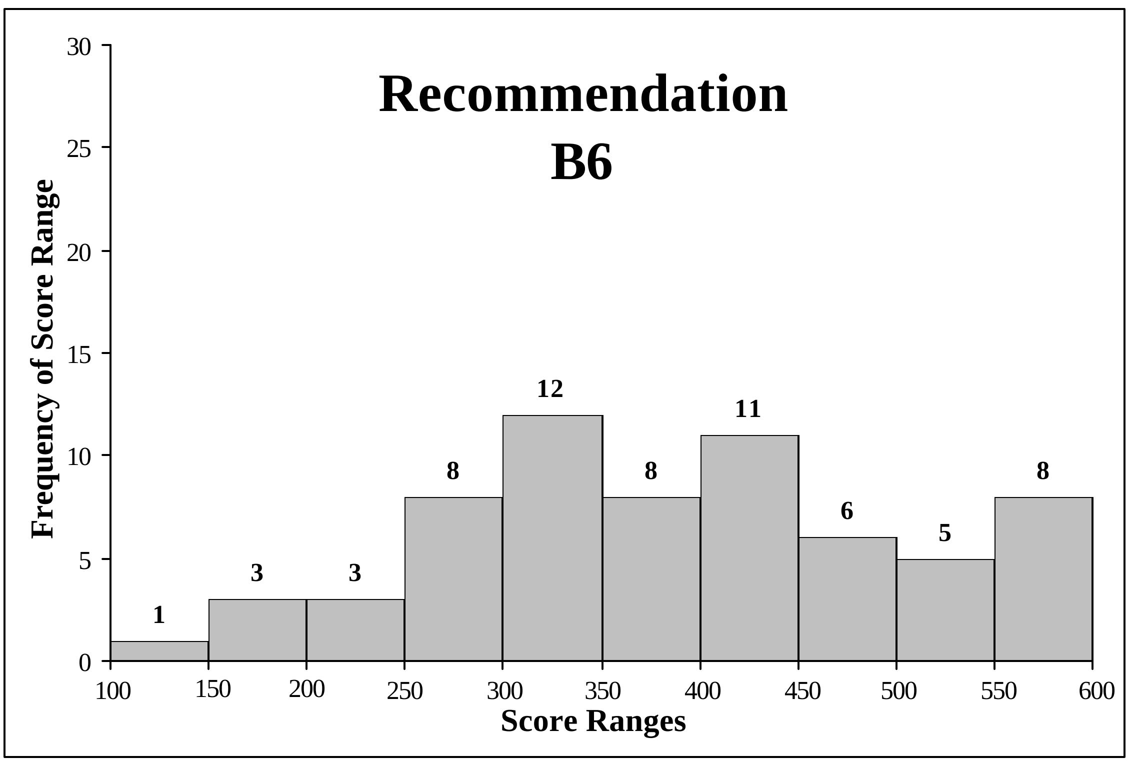
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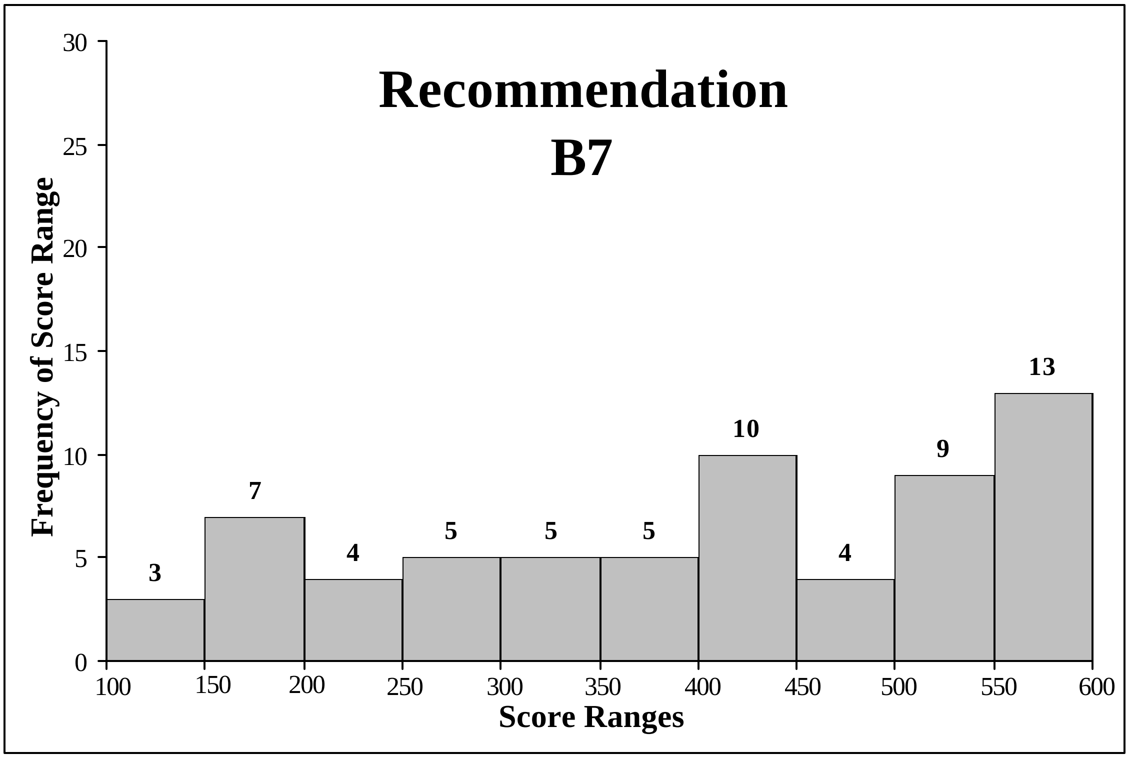
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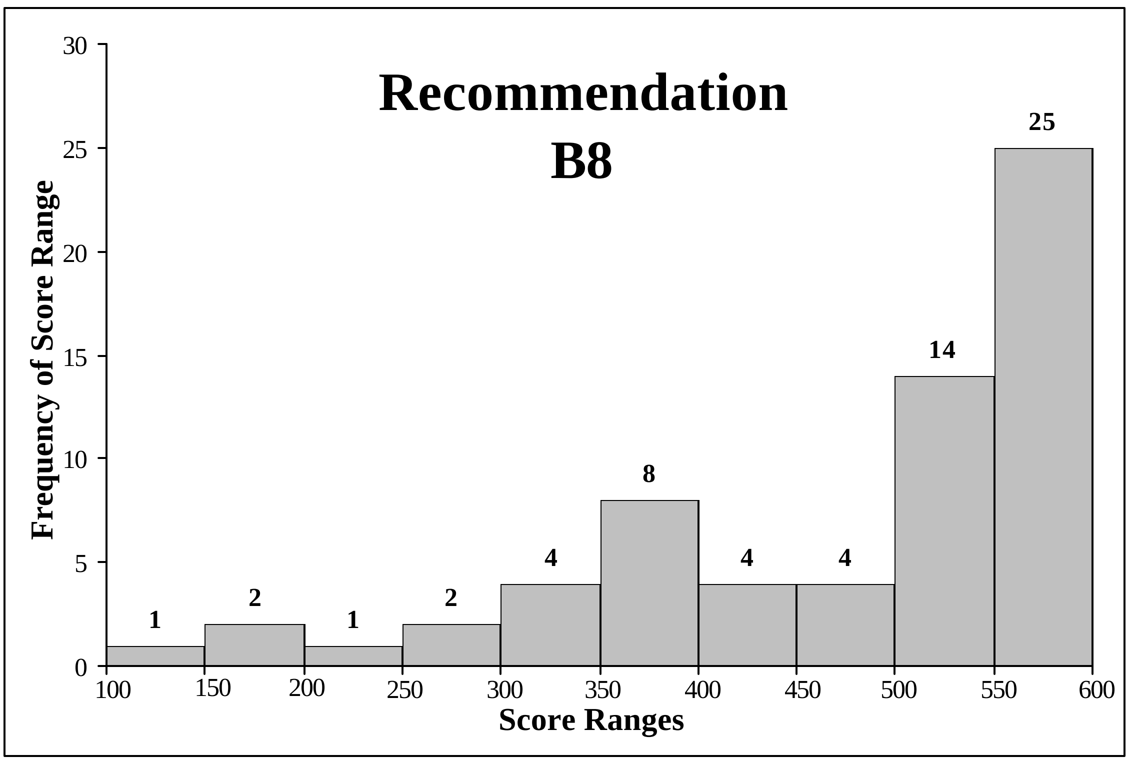
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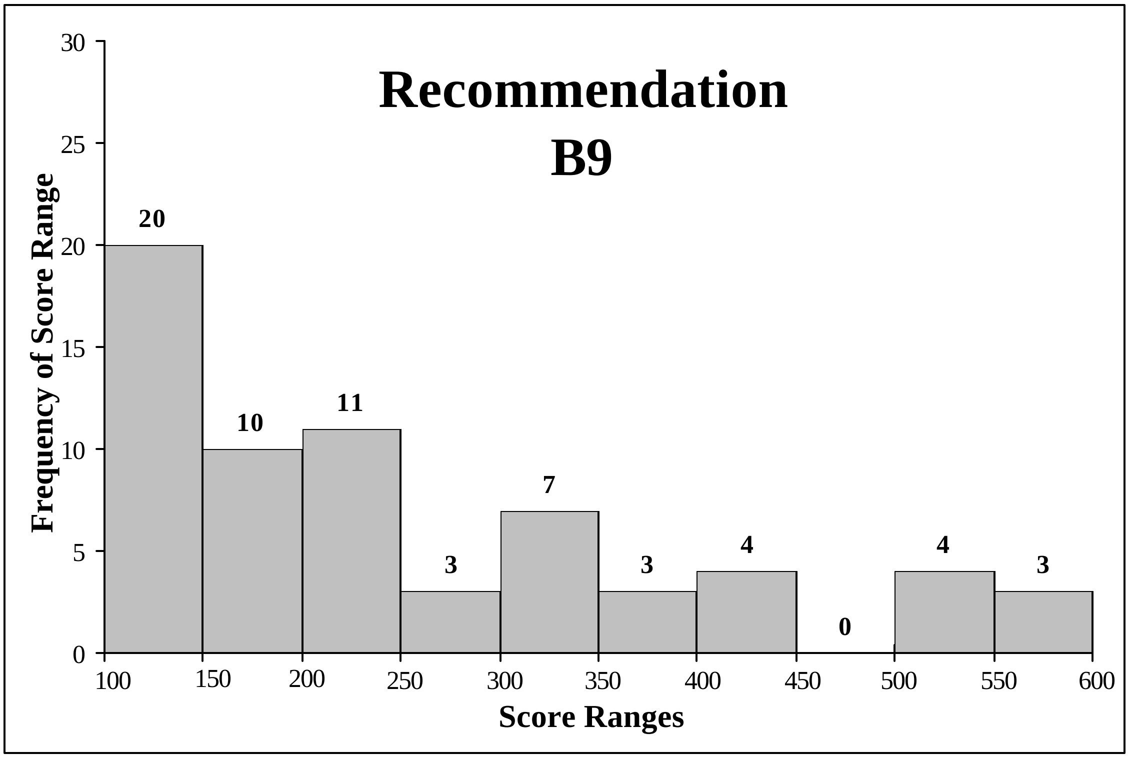
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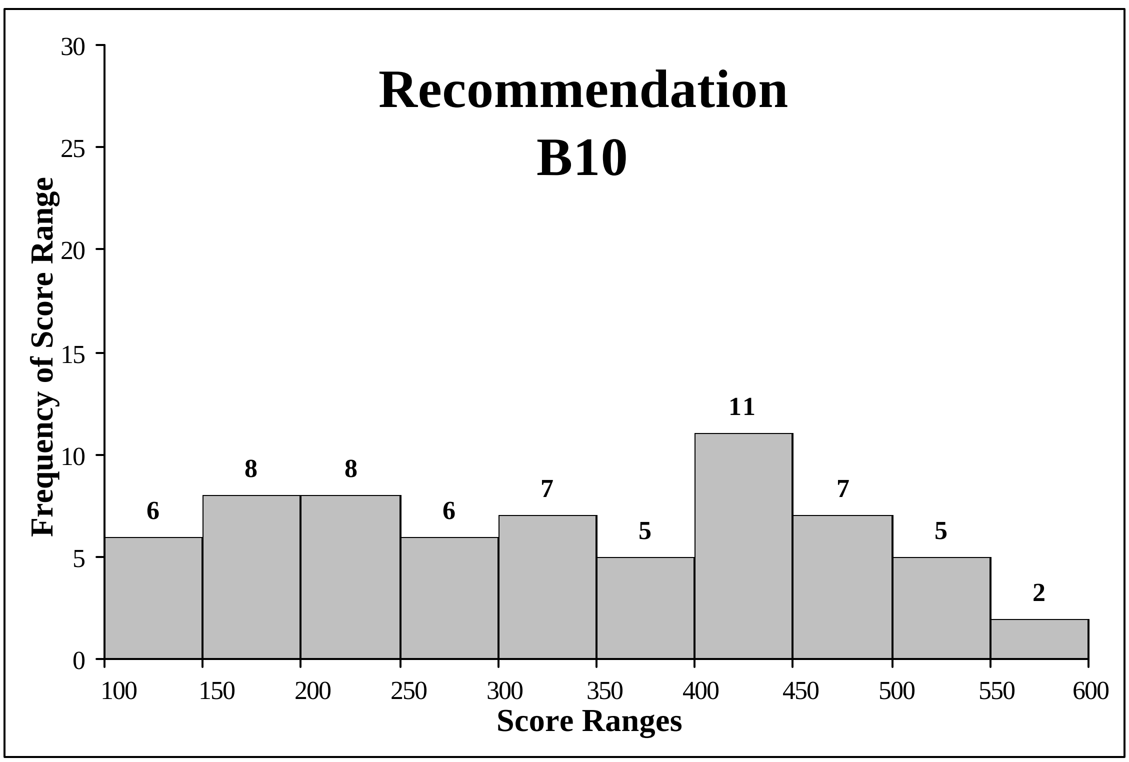
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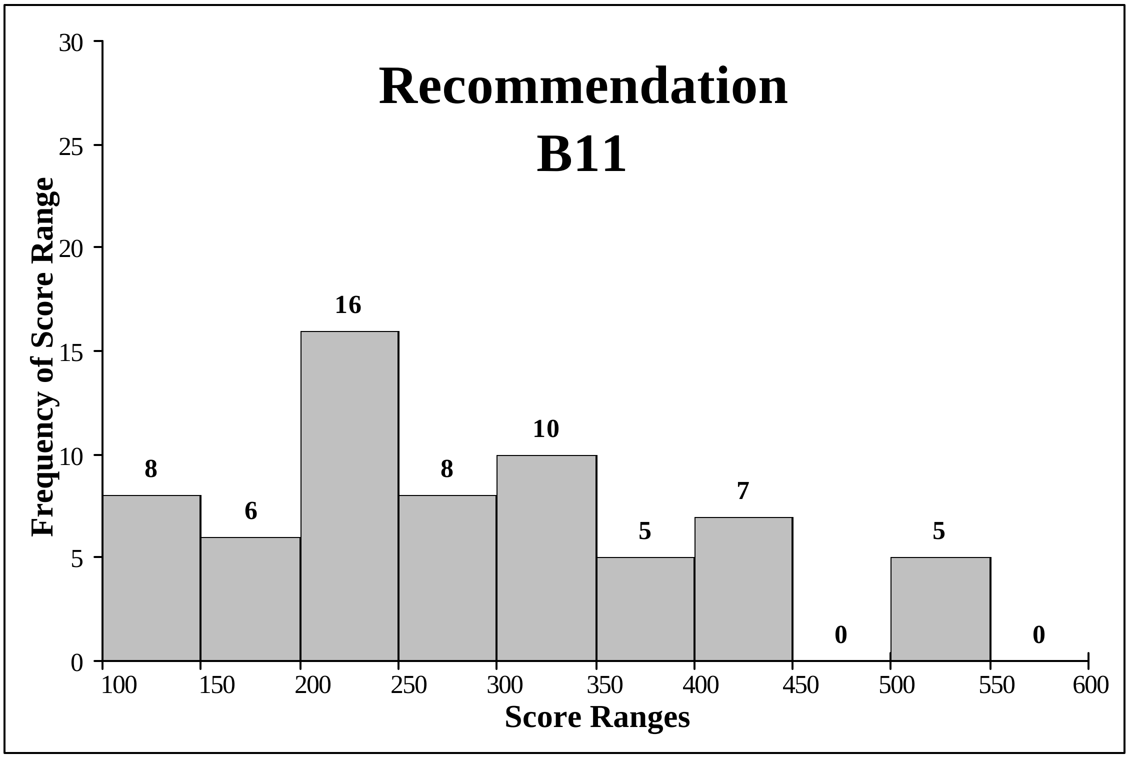
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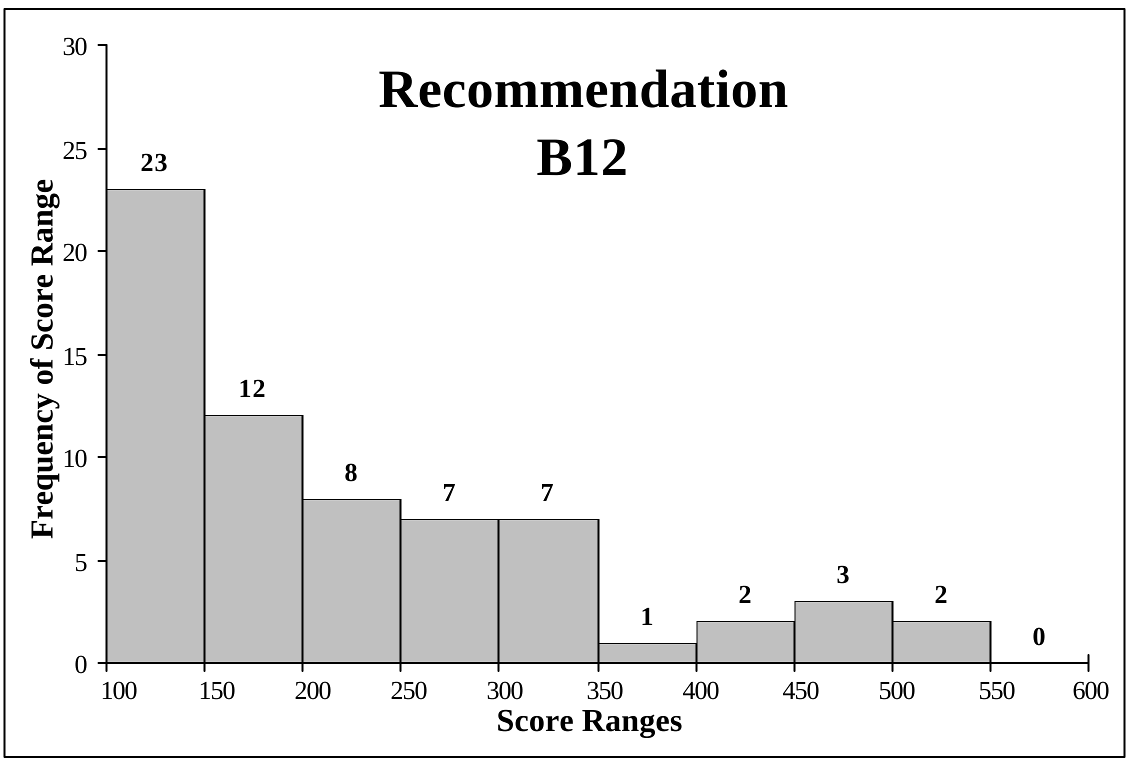
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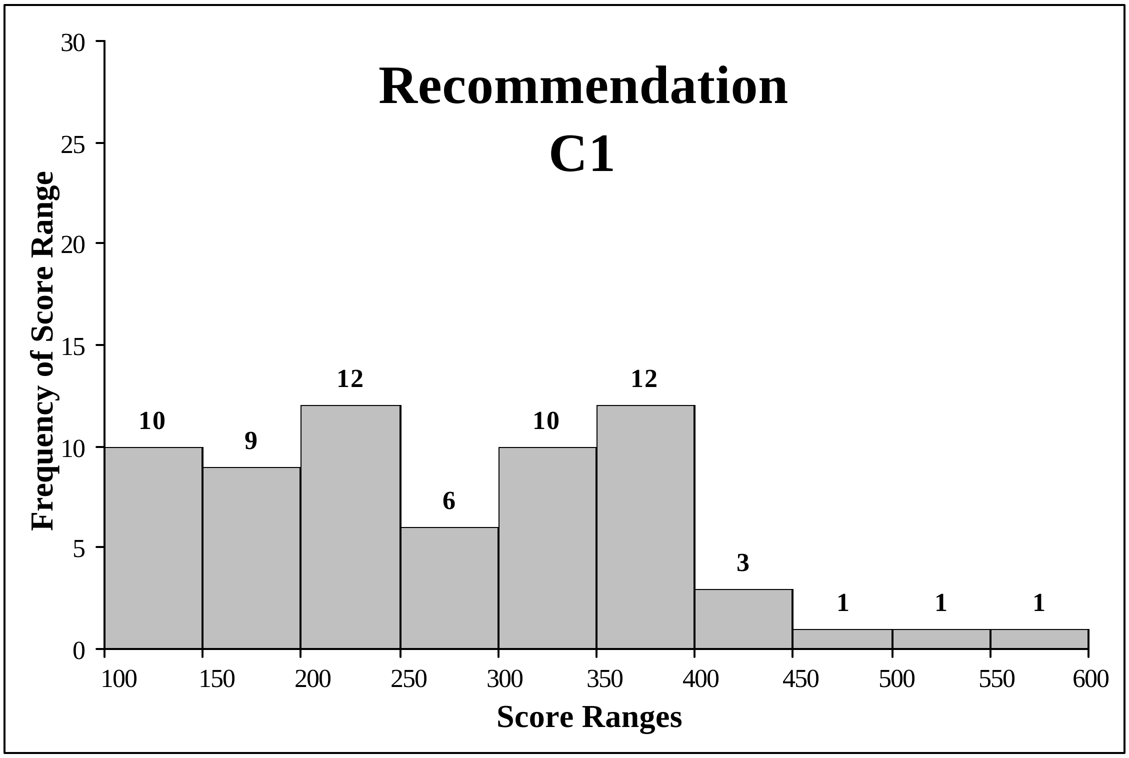
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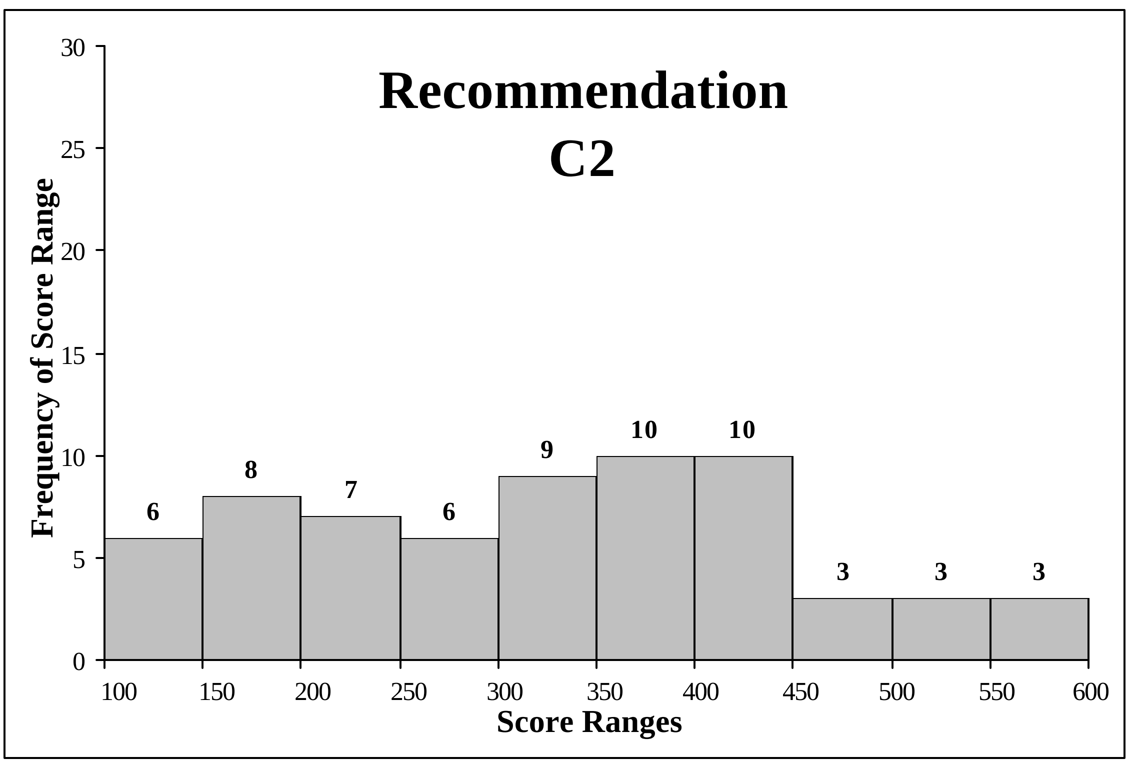
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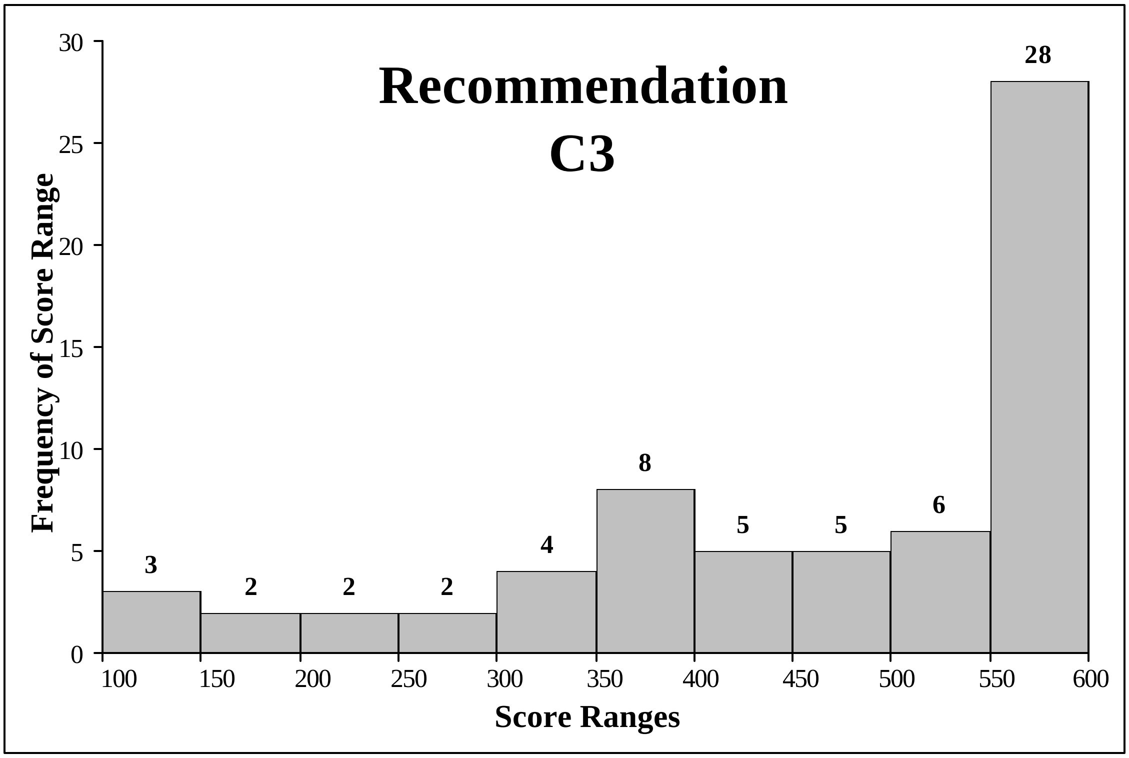
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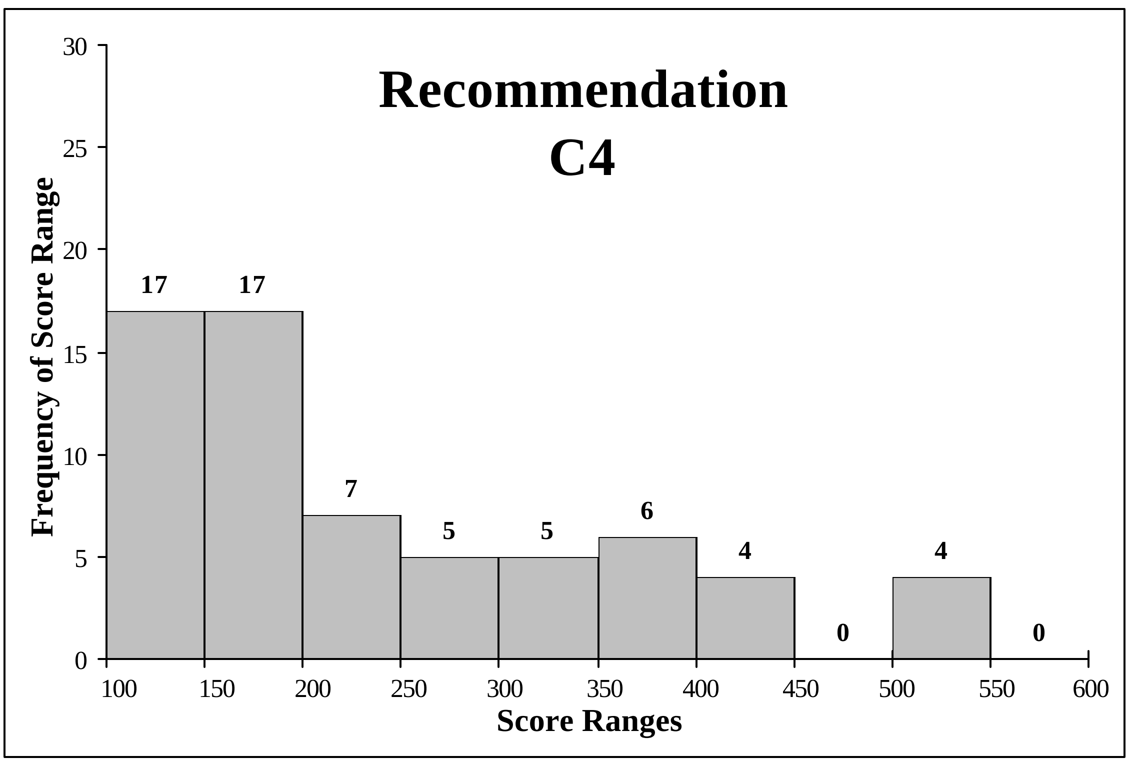
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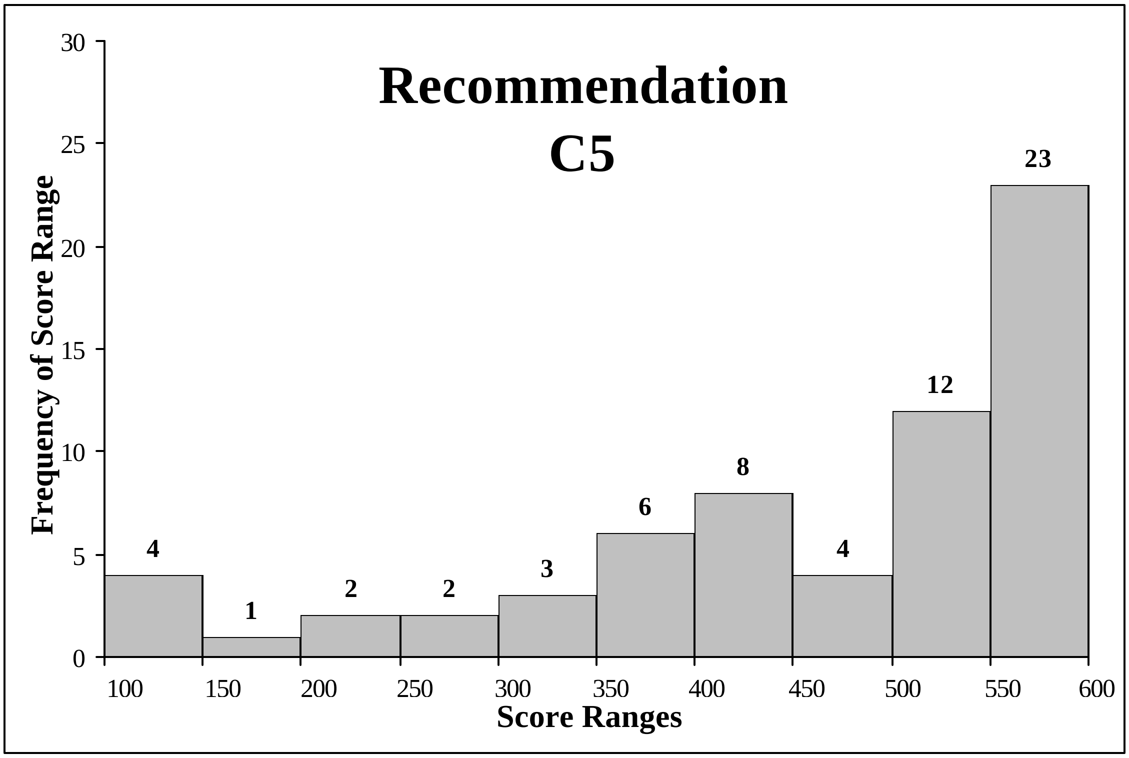
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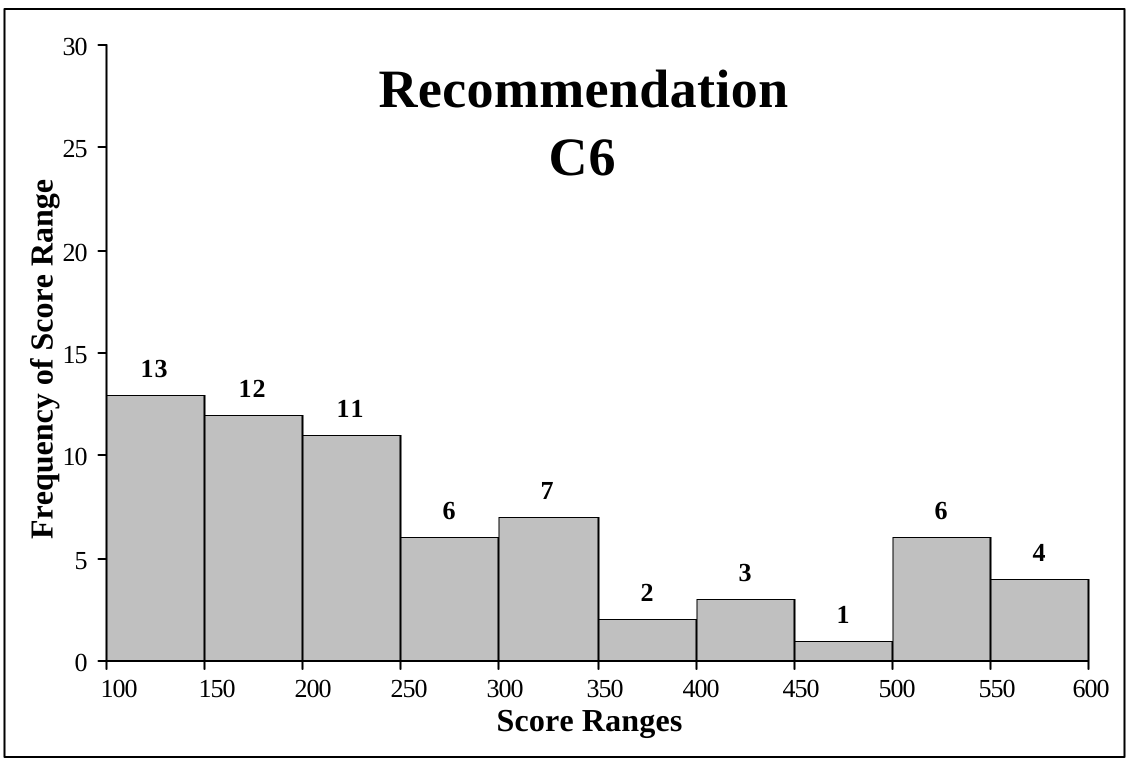
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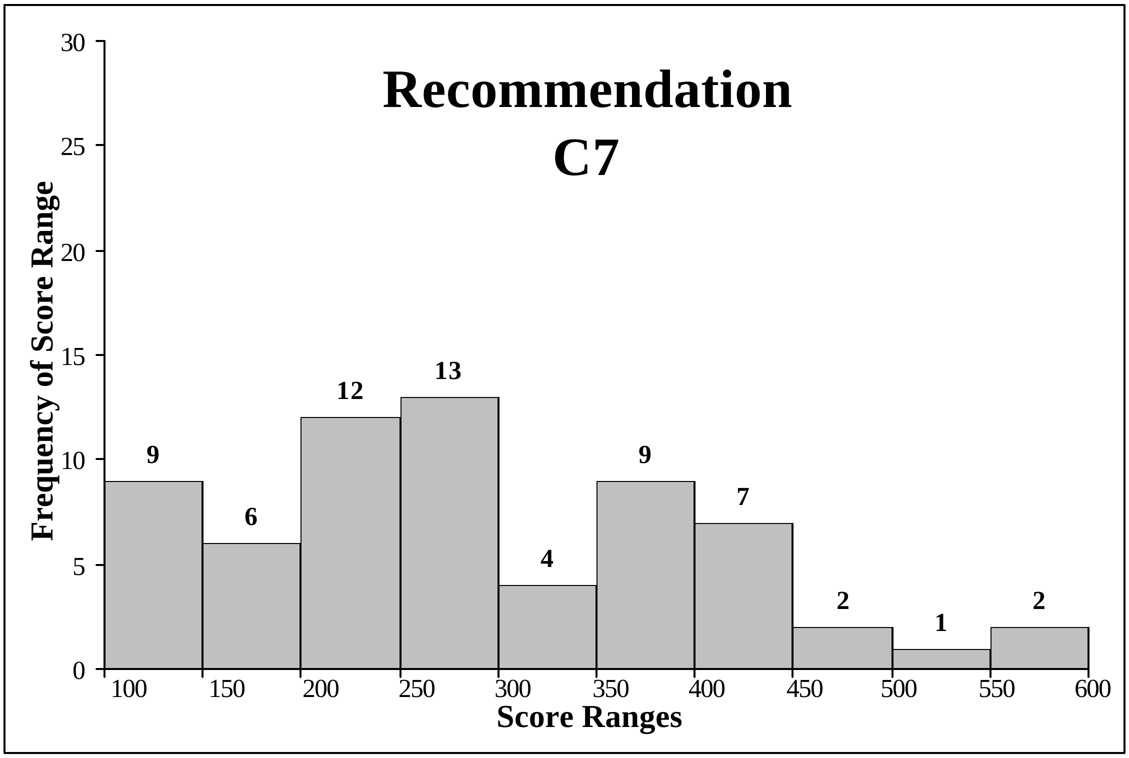
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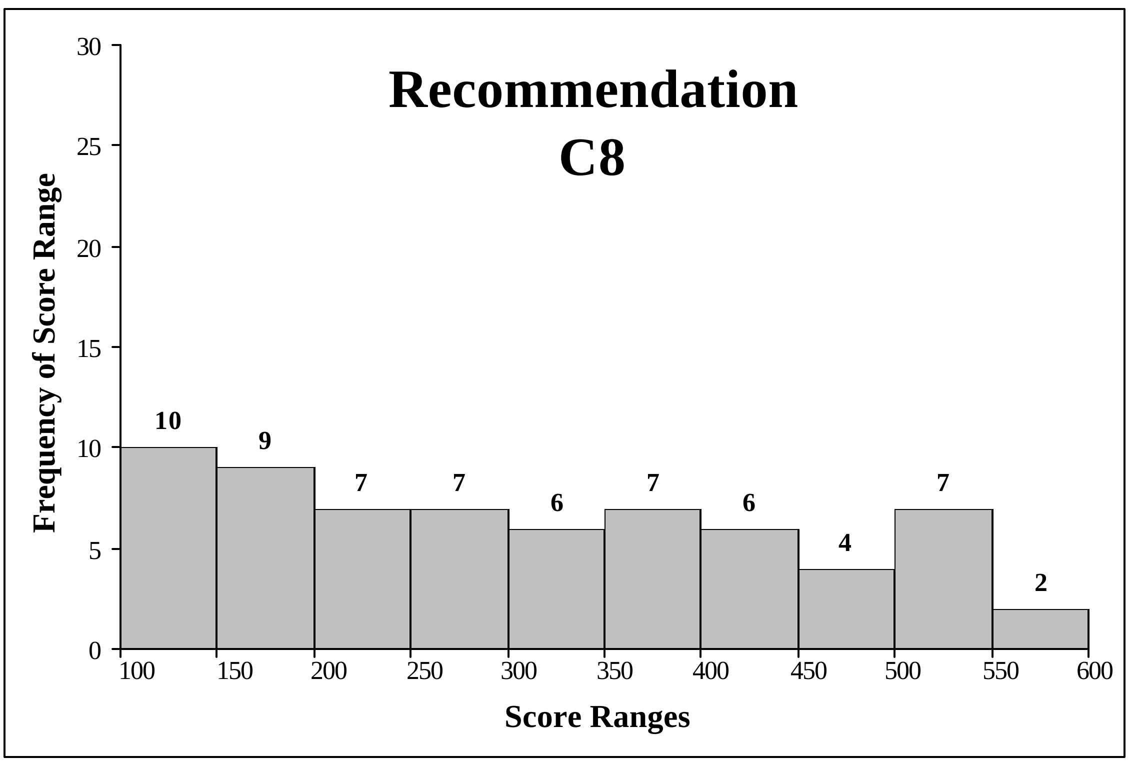
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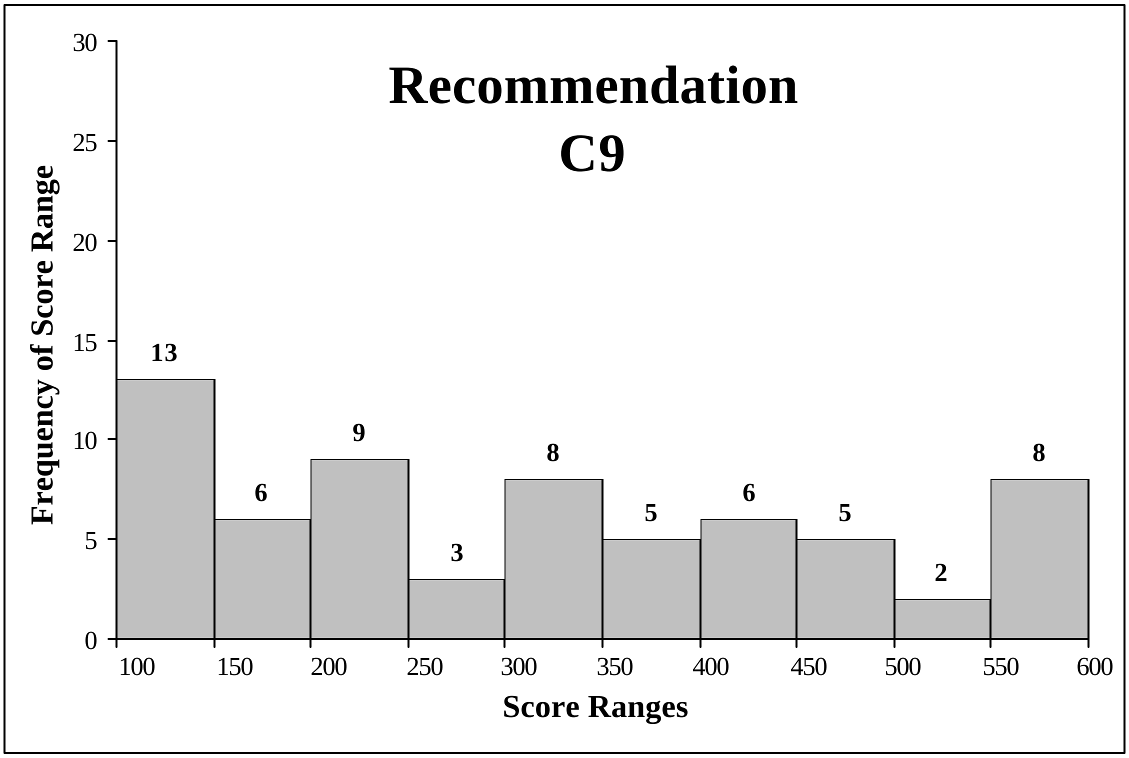
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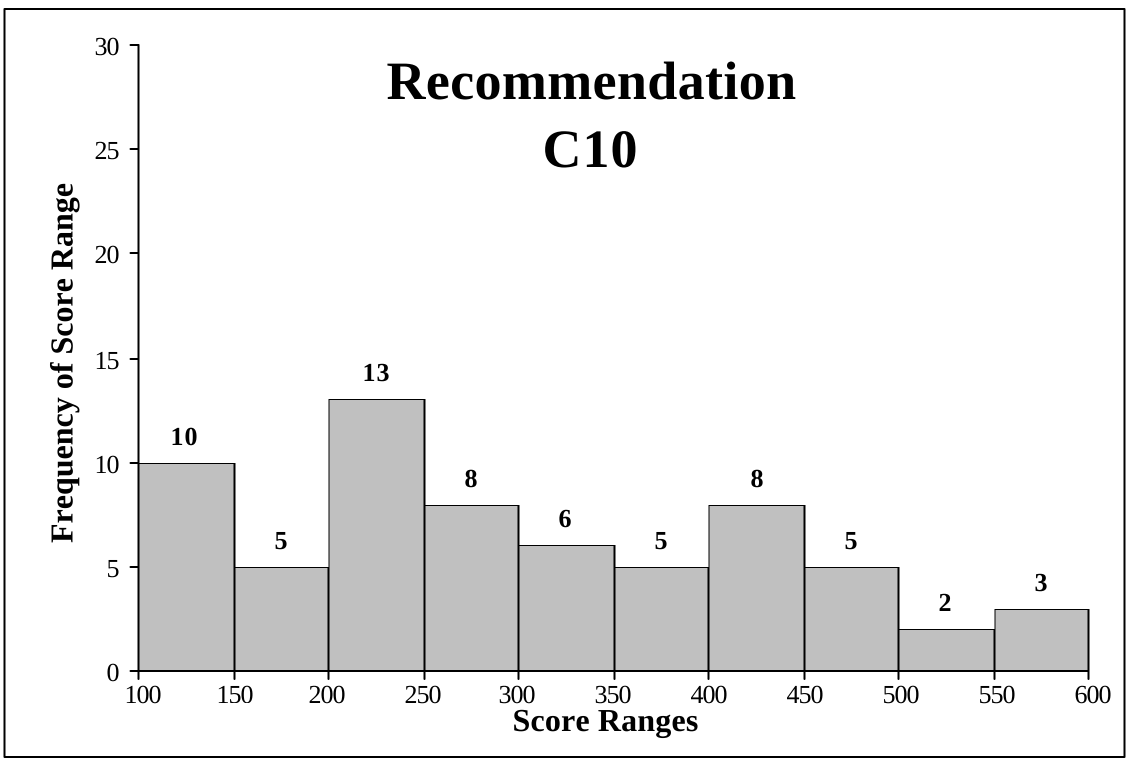
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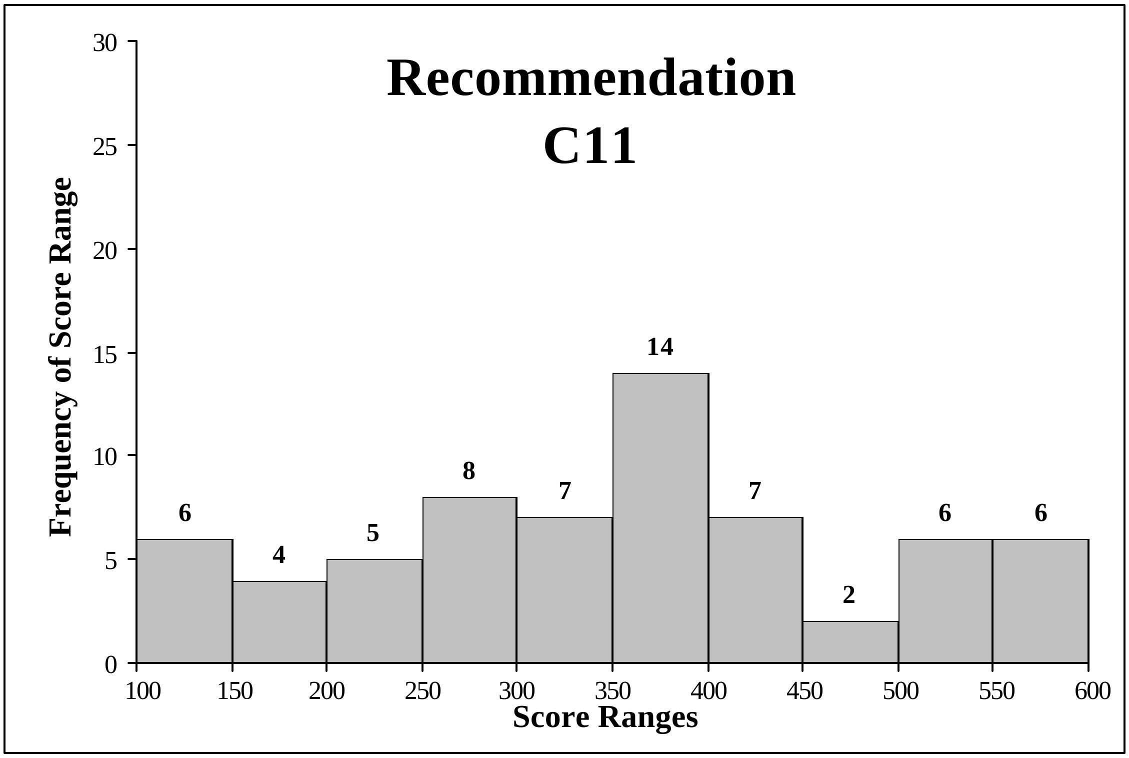
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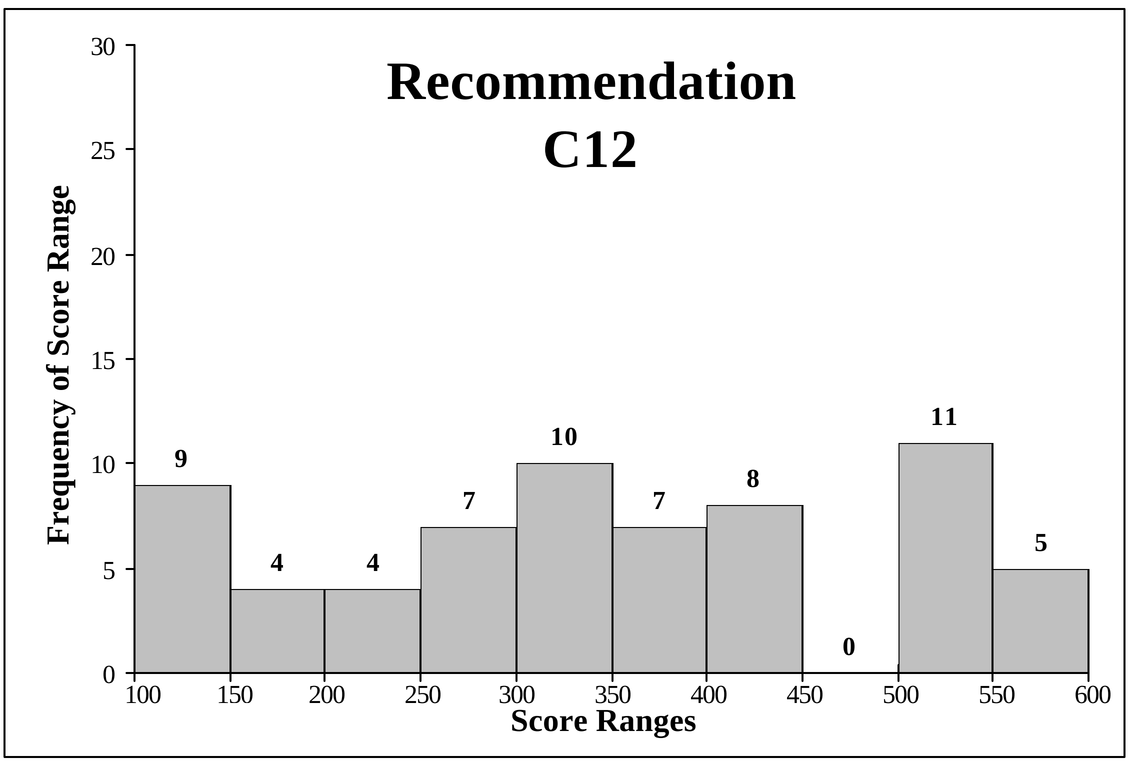
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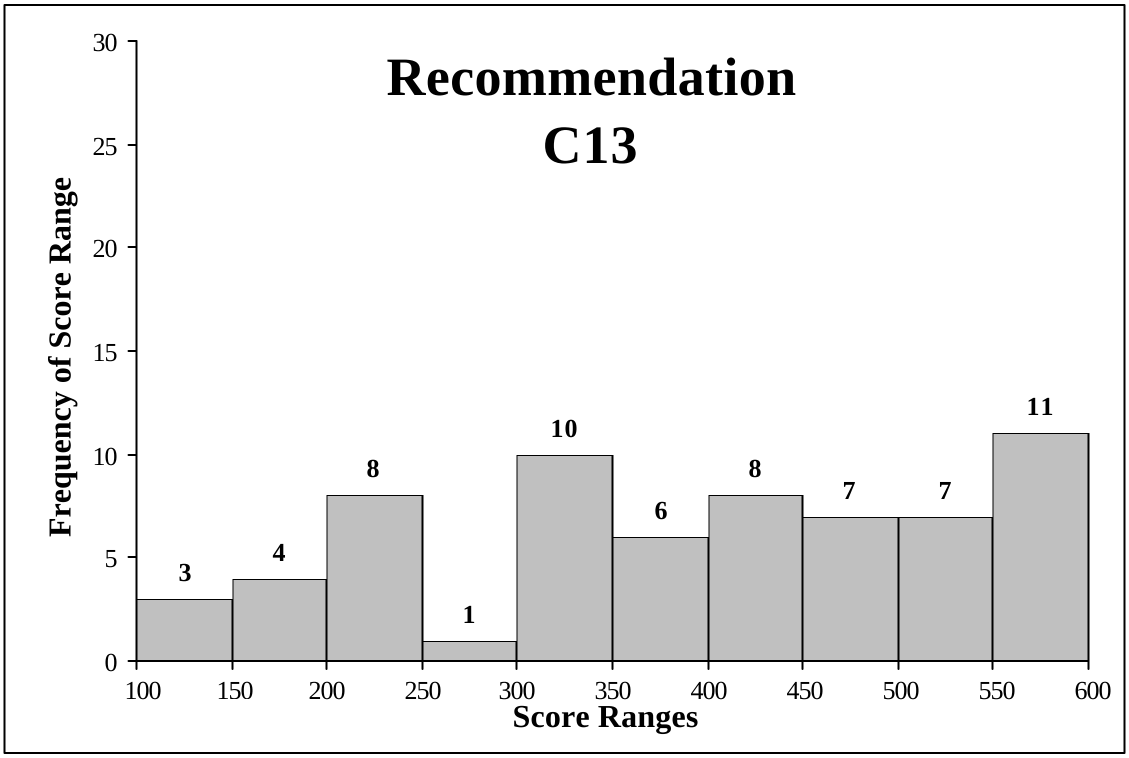
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Appendix B:

The Recommendations

Recommendation Title: Gait Assessment and Clinical Decision Making

Recommendation Code: A1

Category: Research

Recommendation

Background

The National Center for Medical Rehabilitation Research has encouraged the use of movement analysis to aid clinical decision-making and guide the selection of appropriate treatment. Currently, clinicians are using the disability model as a format for clinical decision making. A number of questions, however, need to be addressed to better understand the association between measures of gait and the disability model (i.e., pathophysiology, impairment, functional limitations, disability, and societal limitation). Gait abnormalities have been described for a variety of medical conditions, but their use in guiding clinical decision making has not been documented. This is related, in part, to a lack of knowledge about which gait variables correlate most strongly to improved functional capacity. If different levels of physical impairment could predict a greater likelihood of locomotion disability, this would provide clinicians with objective information to develop effective treatment interventions. In the case of chronic progressive disorders which increase in severity over time, there may be critical periods when intervention may be more efficacious in maintaining or improving functional movement.

Objectives

Improve the efficacy of clinical decision making so that the relationship between gait assessment and various components of the disability model can be established.

Recommended Actions

Establish research funding to develop predictive models that describe the association between gait variables and components of the disability model.

Fund research to identify gait variables which are most useful for clinical decision-making.

Fund research to develop test protocols which are valid and sensitive in describing gait in a wide variety of patient populations.

Obtain funding for fellowship training programs that will provide clinicians with extensive training and experience in making clinical decisions using the disability model.

Recommendation Title: Gait Assessment and Functional Outcomes

Recommendation Code: A2

Category: Research, Training and Education

Recommendation

Background

According to data from the 1989 National Health Survey at least 7.7 million adults are physically disabled and approximately 2.4 million people have difficulty walking or performing other functional mobility tasks. Current gait assessments do not necessarily reflect what locomotive difficulties may exist for a given individual in her/his environment. The usefulness of gait assessment in identifying functional limitations will depend to some extent on the specific protocols or testing conditions used. Moreover, the ability of gait profiles to predict future functional status has not been determined. The NCMRR has encouraged the use of movement analysis to establish meaningful functional outcome measures. The specific relationship between gait assessment and functional outcome measures, however, has not been determined.

Objectives

1) Determine those gait parameters/variables and protocols which are the best predictors of functional outcomes.

- a) Identify gait related measures which relate most directly to improved functional outcomes in a wide array of disease conditions and populations.

2) Determine those gait parameters/variables and protocols which are the best predictors of future functional mobility status.

- a) Conduct epidemiological and longitudinal studies to determine/identify gait parameters that are predictive of future functional mobility status.

3) Transfer this information to appropriate locations including:

- a) Training gait assessment personnel
  Develop fellowship training programs that will provide extensive training and experience in conducting gait assessment which most directly relates to improved functional outcomes.

- b) Educating referral sources
  Disseminate information regarding the established relationship between gait assessment and improved functional outcomes.

- c) Educating reimbursement agencies and policy makers
  Provide and disseminate information regarding the established relationship between gait assessment and improved functional outcomes and lobby for appropriate reimbursement.

Recommended Actions

Develop long-term funding for the above objectives.

Recommendation Title: Is Gait Analysis Efficacious in Improving Treatment Outcomes?

Recommendation Code: A3

Category: Validation

Recommendation

Background

The majority of clinical decisions for improving motor function in individuals with disability are made in the absence of clinical gait analysis. However, a small percentage of rehabilitation professionals (clinicians in the fields of orthopedics, pediatrics, OT, PT, physiatry) routinely utilize gait analysis in their clinical practice. The primary reason for the inconsistent utilization of clinical gait analysis is the lack of efficacy data demonstrating that functional outcomes are improved as a direct result of gait analysis. The consequence of this uncertainty is that individuals with disabilities are either deprived of a useful assessment tool or are subjected to a time consuming and unnecessary evaluation.

Objectives

To demonstrate that clinical gait analysis alters treatment decisions so at to improve functional outcomes within specific diagnostic categories.
Research must accomplish the following:

1) Compare and contrast the effectiveness of clinical practice in the presence or absence of gait analysis.

2) Identify which patient categories objectively benefit from clinical gait analysis.

3) Replicate the findings to determine whether the results from particular studies are consistent and generalizable.

Recommended Actions

Support research that documents that clinical gait analysis improves functional outcome within specific diagnostic categories. This research is of relevance to NIH, the VA and private funding agencies.

Recommendation Title: Accuracy, Precision and Validity of Movement Analysis Techniques

Recommendation Code: A4

Category: Validation

Recommendation

Background

Recent advances in instrumentation and computer technology have substantially increased the accuracy and precision of the fundamental data collected in movement analysis. However, this technological progress has not necessarily produced corresponding improvements in the information that is available for clinical interpretation. This is because relatively few studies have comprehensively identified the real and potential artifacts inherently involved in transforming the basic collected data set (e.g., spatial location of body markers) into assessment variables (e.g., joint angles). These include the errors associated with the placement and use of "instruments" on patients, the adequacy of data reduction approaches (e.g., models), and patient performance variability. Consequently, the clinical team is often faced with the dilemma in data interpretation of distinguishing measurement artifact from movement abnormality without sufficient confidence in the data collection and reduction processes. Moreover, it is important to appreciate that the usefulness of future developments in clinical movement analysis (e.g., simulation using musculoskeletal modeling) can be substantially enhanced by an explicit treatment of these issues.

Objectives

To document the inherent limitations and uncertainties associated with clinical movement analytical protocols and techniques, to investigate their effects on the information made available for clinical interpretation, and to develop new approaches that improve the quality of movement information with respect to accuracy, precision, sensitivity, and reproducibility. This is to include the systematic examination of:

1) The application of movement analysis instruments and protocols.

2) The processes and models used to reduce the collected data.

3) The variability of patient task performance.

Recommended Actions

1) It is recommended that NCMRR make funds available to support the objectives stated above.

2) It is also recommended that issues of accuracy and precision be considered as part of any movement analysis laboratory accreditation process.

Recommendation Title: Evaluation of Clinical Interventions Using Functional Movement Analysis and Disability Measures

Recommendation Code: A5

Category: Clinical Research

Recommendation

Background

Rehabilitation interventions such as surgery, therapies, and assistive devices are widely recommended in treatment of patients with disability. Currently, there are very few quantitative data to justify treatment recommendations to patients, health professionals, and third party payers. For interventions impacting mobility, functional movement analysis is one quantitative tool which can be useful both in designing clinical trials to validate clinical practices, and in treating individual patients.

Movement analysis has the ability to quantify the mechanics of movement and demonstrate how interventions alter mechanics. However, movement analysis alone does not adequately describe the overall functional and disability status of the patient. Consequently, in the evaluation of treatment alternatives it is important to include a variety of quantitative functional assessment approaches which include both descriptors of the mechanics and pathophysiology of movement and activity, and disability measures. The simultaneous use of these assessment strategies moves gait analysis beyond the laboratory setting and, thus, further elucidates the relationship between underlying mechanisms and function.

Using gait analysis to answer clinically relevant questions will define its role in the clinical and investigatory armamentarium; likewise its thoughtful and discriminating application can strengthen the role of rehabilitation in its broadest sense by providing firm data to justify management approaches.

Objectives

Objectively evaluate treatment alternatives in the clinical management of persons with a variety of impairments using functional movement analysis and disability measures.

Recommended Actions

Fund clinical protocols addressing efficacy of rehabilitation interventions which incorporate functional movement analysis measures and disability measures as clinical evaluation tools.

Recommendation Title: Development of Standards for Management of Clinical Movement Analysis Data

Recommendation Code: A6

Category: Standardization

Recommendation

Background:

In the field of clinical movement analysis there are variations in nomenclature and technique for data acquisition and reduction. A variety of acceptable data acquisition and reduction techniques exist. This makes quality control difficult. It is not necessary for all laboratories to use the same data acquisition and reduction technique, but the technique used should be identified when clinical results are disseminated, and should conform to quality control standards. Unfortunately, such standards are presently not available.

A second concern is the large variety of methods for presenting clinical results. This may lead to misinterpretation of results, as well as poor communication between laboratories and among movement analysis specialists. If a uniform presentation method were used, then results could be more effectively interpreted by all movement analysis specialists, and results from laboratories could be directly compared to published results.

Objectives

1) Establish quality control standards for data acquisition and reduction.

2) Establish standards for nomenclature in movement analysis.

3) Establish a uniform method for presenting clinical parameters and movement analysis results.

Recommended Actions

Fund a workshop to provide a consensus regarding standardization of quality control for data acquisition and reduction, nomenclature, and uniform presentation methods. This workshop should result in the publication of these standards.

Recommendation Title: Development of Timely and Objective Methods of Acquisition, Reduction, and Interpretation of Movement Analysis Data

Recommendation Code: A7

Category: Technological Development

Recommendation

Background

The future of movement analysis lies in the ability to process data quickly, and objectively interpret movement analysis data. Currently the manual labor needed to acquire, reduce, and interpret data is time consuming. Furthermore, the time availability of clinicians to perform this task is often limited adding to the delay in report processing. This drives the cost of analysis up and increases the turn around time for clinical decision-making. Another issue is that considerable subjectivity exists in the interpretation process. The quality and effort needed to properly define abnormalities and compensatory processes, as well as the identification of relationships between deviations and their functional significance often vary widely with the education and expertise of the clinician. Current methods for visualization of movement analysis data are not intuitive to health professionals. All of these factors serve as a deterrent to the widespread use of clinical movement analysis. Computer and electronic based technology may provide the means to address these inadequacies.

Objectives

1) Decrease the cost and expand the field of movement analysis by developing techniques which will provide movement analysis data in a timely fashion (real time).

2) Develop new techniques for acquiring and reducing movement analysis data.

3) Develop innovative methods for displaying movement analysis data which will be intuitive to clinicians.

4) Provide opportunities for educational training for those who interpret movement analysis data.

Recommended Actions

1) Provide a funding mechanism for the development of movement analysis systems which will:
- process data in a timely fashion.
- utilize new techniques for acquiring and reducing movement analysis data.
- incorporate accurate and objective interpretation methods.
- display the information in a way that is intuitive to the clinician.

2) Provide a funding mechanism for the development of educational methods, which may include interactive computer-based training approaches, to ensure highly qualified personnel for data interpretation.

Recommendation Title: Development of a System Network for Sharing Movement Analysis Data Files

Recommendation Code: A8

Category: Standardization and Interpretation

Recommendation

Background

Movement analysis laboratories have limited data to draw on for experience. Movement analysis data transfer is difficult because of differences in methods of data acquisition and reduction, and differences in data formats. Diagnostic analysis is difficult because of limited populations at each laboratory. There is currently no system network for sharing movement analysis data between laboratories.

Objectives

1) Transfer movement analysis data to assist in diagnostic assessment.

2) Document differences in data acquisition and reduction.

3) Maintain patient and clinician confidentiality.

Recommended Actions

1) Establish a system network of transferring movement analysis data files.

2) Establish the need for continuing support of the system network.

3) Establish rules and safeguards for participation in and access to the data.

4) Establish data file formats, discuss formats with different vendors, and consider the need for format conversion software.

5) Require documentation of data acquisition and reduction techniques of participating laboratories.

6. Insure patient and physician confidentiality.

Recommendation Title: Education and Training of Personnel Involved in Gait Analysis

Recommendation Code: A9

Category: Education

Recommendation

Background

The proper performance and analysis of movement disorders by objective measures of movement analysis requires a broad range of basic knowledge in a variety of fields. Such areas include an understanding of medical disorders and its pathophysiology, fundamental physiology and neurocontrol of human movement, and basic principles of physics and engineering mechanics. Applying the knowledge in each of these areas in an interdisciplinary manner to the field of movement analysis is also essential. There is no opportunity to obtain this diverse training by current educational training approaches and limited time availability in already crowded personnel and academic schedules. Furthermore, the availability of highly trained individuals to provide the appropriate educational experience is limited. Therefore, emphasis must be placed on the provision of new alternative educational opportunities.

Objectives

To provide adequate cross-disciplinary education and training in the fields of medicine and engineering to both those engineers and clinicians as well as the medical community at large who provide care for persons with locomotion disabilities

Recommended Actions

It is recommended that NCMRR provide research funding for supporting the development of new educational opportunities and approaches, including computer-based teaching tools, research training fellowships, and instructional teleconferencing workshops and courses to insure that movement analysis is fully utilized and optimally applied. Funding recipients would require excellence in medicine, engineering, movement analyses as well as advanced methods in education.

Recommendation Title: Determinants of Gait-Related Pathology

Recommendation Code: A10

Category: Research

Recommendation

Background

Gait analysis often involves numerous types of assessments such as pressure measurements, kinematics and dynamic electromyography. These result in potentially thousands of numbers which represent various aspects of one's gait. There is a lack of clear understanding of which parameters are most relevant in the etiology of a specific pathology. For example, loading rates of force, rather than peak forces may be more critical to the development of a lower extremity stress fracture. The identification of commonly used variables, along with the development of new biomechanical variables which characterize gait is needed. In addition, a person's structure is inherently related to their mechanics. Yet the exact manner in which abnormal structure impacts mechanics is yet to be understood. A greater knowledge of the structural and biomechanical variables related to a pathology will improve the efficacy of gait analysis and provide clinicians with a clearer focus on how to direct their clinical interventions.

Objectives

Increase the understanding of the structural and biomechanical causes of gait-related pathology so that enhanced treatment interventions and preventative measures can be developed.

Recommended Actions

Develop funding mechanisms to support research aimed at the identification of relevant structural and biomechanical variables which are correlated to pathologies associated with locomotion.

Recommendation Title: Development of Models to Study the Relationship Between the Observed Abnormal Gait, Lower Extremity Structure, and Underlying Etiology

Recommendation Code: A11

Category: Research

Recommendation

Background

The vast majority of individuals with neuromusculoskeletal pathologies present clinically with aberrant activities of daily living (ADL), posture and/or locomotion. Currently clinical gait analysis does a good job identifying what the abnormalities are in a patient's gait for a limited subset of neuromusculoskeletal pathologies. Abnormalities in movement patterns, joint moments and timing of muscle activity can all be measured and documented. Gait Analysis does less well, however, at definitively identifying the underlying cause or long-term consequences of a specific abnormality in the gait pattern. In specific, distinguishing compensation from primary problems often depends highly on the experience and intuition of the interpreting clinician.

The role of lower-extremity structure in biomechanical function and pathomechanics also needs to be evaluated. The particular alignment and orientation of the joints within the lower extremity is critical to the overall function of the kinetic chain. For example, is the alignment and orientation of the knee important to the etiology, severity and treatment of knee Osteoarthitis (OA)? Does foot and ankle malalignment contribute to knee OA?

The difficulties in establishing a cause and effect link between gait abnormalities, aberrant structure, and pathology stem from deficiencies in the knowledge of the mechanics and neural control of normal and pathological gait. Neuromusculoskeletal models can provide a theoretical framework from which to study this relationship for a given pathology. This knowledge and objective gait data will enhance the assessment, treatment planning, and prognostic capabilities of clinicians who manage patients with impairments, functional limitations, and disabilities.

Objectives

1) To improve models of the neuromusculoskeletal system and their validity for simulating lower extremity function, pathomechanics, and neural control. These models may be comprehensive or pathology specific and include but not be limited to; osseous geometry, soft tissue material properties, muscle dynamics, skeletal dynamics, and neural control.

2) To utilize these models to improve our knowledge of how the structure, control, and neuromusculoskeletal dynamics contribute to the pathomechanics of patients with impairments, functional limitations, or disabilities.

3) In conjunction with movement data utilize these models to develop techniques to definitively identify the underlying cause and long-term consequences of a specific abnormality in a patient's gait pattern.

Recommended Actions

It is recommended that agencies develop funding mechanisms to support research to meet the above objectives.

Recommendation Title: The Scope of Movement Analysis

Recommendation Code: A12

Category: Overall

Recommendation

Background

Historically, the term "gait analysis" has been used in a number of different contexts. The use of kinematic analysis, kinetic analysis, and dynamic EMG in the setting of cerebral palsy has been the application that most observers would associate with gait analysis. However, a wide-range of possibilities exists - in terms of the indications, instrumentation, candidate movements, and candidate pathologies to which movement analysis can be applied.

Objectives

To broaden the scope of gait analysis to include the multifactorial analysis of movement in the many contexts that have rehabilitation medicine as their common denominator.

Recommended Actions

It is recommended that the following be included as being within the scope of gait analysis:

Indications:

- Prevention
- Diagnosis
- Treatment planning
    - Medication
    - Surgery
    - Rehabilitation
    - Exercise prescription
    - Footwear prescription
    - Orthotic and assistive device prescription
- Use as an outcome measure
- Treatment *per se* (feedback)
- Evaluation

Instrumentation:

- 2D kinematic analysis (where appropriate)
- 3D kinematic analysis
- Ground reaction force measurement
- Accelerometry
- Electromyography
- Metabolic measurement
- Plantar Pressure measurement
- Instrumentation of walking aids
- Instrumentation of stair rails
- Long term gait monitoring
- Muscle force estimates
- Inverse dynamic models
- Forward dynamic models

- Virtual reality
- Visualization
- Speed and timing parameters

Candidate Movements:

- Gait
- Upper extremity motions
- Trunk motion
- Lifting
- Wheelchair propulsion
- Non straight line walking
- Non steady speed walking
- Chair rise
- Posture and balance
- ADLs
- Instrumental ADLs
- Grade locomotion
- Ramps
- Stairs
- Load Carrying
- Fall prevention
- Feedback as a treatment
- Prosthetic and orthotic fitting and familiarization
- Return to full activity (including athletics and sport)
- Transfers

Candidate Pathologies:

- Cerebral palsy
- Stroke and all other UMN diseases
- LMN diseases
- Arthroplasty
- Amputation
- Fall risk assessment
- Sports injury
- Cumulative trauma disorders
- Diabetic foot disease
- Arthridities
- Sarcopenia
- Orthopedic trauma
- Basal ganglia disorders
- Other disorder affecting movement

Recommendation Title: Expand the Clinical Application of Gait Analysis

Recommendation Code: B1

Category: Application

Recommendation

Background

Gait analysis has been demonstrated to be effective in guiding the selection of orthopedic surgical procedures for individuals with cerebral palsy. Other neuromusculoskeletal and medical pathologies that have not adequately responded to standard forms of care addressing functional limitations and disability may also benefit from gait analysis. For example:

1) In patients requiring surgery after ineffective non-operative management of medial knee compartment osteoarthritis, gait analysis can select the appropriate patients for high tibial osteotomy vs. total knee replacement.

2) Gait measurements of plantar foot pressure in individuals with diabetes mellitus suggests that it may be an effective method for both identification and load relief prescription in those individuals where standard tissue management have failed.

3) Focused treatment following the identification of specific hip and ankle weakness via gait analysis in patients post stroke, demonstrated significant improvement in gait. Gait analysis used in this manner should be explored to identify specific treatment focus.

4) The custom of using comprehensive analysis by most laboratories presents a model which may not be appropriate for use in all pathologies. Therefore, new models need to be developed for other pathologies. The use of gait analysis to improve clinical decision-making should inevitably improve individuals outcome.

Objectives

1) To demonstrate the contributions of gait analysis to treatment planning, decision-making functional outcome and subsequent reduction in long-term cost.

2) To target appropriate populations, identify their functional limitations and select treatment interventions which require assessment and reassessment.

Recommended Actions

1) Federal Government should support research that documents effectiveness of gait analysis in identifying functional limitations in new populations (specific testing for specific diagnoses).

2) Federal Government and third party payers should support research that delineates specific gait analysis techniques/tools for specific diagnostic groups (DRG's).

3) Federal Government should support dissemination of findings from research to consumers as well as professionals.

Recommendation Title: Gait Analysis as a Cost Effective Patient Management Tool

Recommendation Code: B2

Category: Finance and Policy

Recommendation

Background

Gait analysis has been shown to be an effective assessment tool. Nonetheless, the cost effectiveness of the tool has yet to be demonstrated as it relates to an individual's functional limitation and disability level. The lack of information on cost effectiveness over the life-span of individuals has impeded our ability to justify the benefits of gait analysis to the consumer, medical community, insurance and insurance providers. As an example of a potential cost saving benefit, a preliminary study has shown that gait analysis intervention which identifies lower limb dysfunction can break the cycle of recurrence in patients with low back pain. Thus lifetime expenditure due to work loss can be diminished. High medical and social costs in this and other pathologies may be positively impacted by proper gait analysis awareness and utilization.

Objectives

To determine cost effectiveness for optimum patient management by identifying selective gait analysis utilization and enhancing both professional and consumer awareness.

Recommended Actions

1) Support research that demonstrates the clinical effectiveness and cost effectiveness of gait analysis for neuromusculoskeletal and medical problems.

2) Fund educational mechanisms to disseminate information to consumers, medical / health professionals, scientists and insurance providers on the appropriate uses of gait analysis and financial cost effectiveness.

Recommendation Title: Use of Gait Analysis Technology as Treatment

Recommendation Code: B3

Category: Applications

Recommendation

Background

Gait analysis has traditionally been used for treatment planning and assessment. One possible area of clinical usefulness could be in the treatment arena, through biofeedback, virtual reality, sensory augmentation, etc. Use of biofeedback has frequently been noted to be an effective treatment tool. Today's technology would permit the investigation of real-time feedback of biomechanical gait variables.

Objectives

To identify areas in which biomechanical analysis may provide treatment options for individuals with various disabilities.

To develop the technology to generate biomechanical information in real time.

Recommended Actions

Support investigations of the use of biomechanical analysis as a treatment tool for individuals with various neuromusculoskeletal disorders.

Sponsor studies that compare clinical outcome of treatment strategies that include biomechanical analysis with established treatment strategies.

Recommendation Title: Clinical Motion Analysis Data Bank with Patient Profiles

Recommendation Code: B4

Category: Resources and Collaboration

Recommendation

Background

Currently, long-established laboratories enjoy the benefit of large individual gait data repositories for comparison of individuals to past experience. Newly developing laboratories could benefit from this past experience if there were a mechanism for data sharing. The Ohio State University (OSU) has a database with the results of initial gait studies on patients with cerebral palsy-spastic diplegia. These data have been accessible, with permission from OSU, only to members of the five laboratories that contributed to the database. These groups found the process useful in developing a process for sharing data and standardizing measurements. Another database with patient problems and responses to treatment for patients with myelodysplasia exists at the University of Washington. Although this database does not contain the motion analysis results per se, it has still proven a valuable national resource for treatment planning in these cases. There are other databases at gait laboratories around the country, and in addition, databases on spinal cord injury and traumatic brain injury exist at model systems that could be studied. Development of a motion analysis database that combines the motion analysis results with the patient problems and treatment outcomes for a variety of diagnoses would prove a valuable resource for existing and developing gait laboratories. This database would facilitate treatment planning and implementation and could serve as a valuable multi-site research tool.

Objectives

Develop a data bank to be shared among participating motion analysis laboratories. At a minimum, this data bank should be designed to allow input specifying the following: lab of origin and equipment and procedures used, patient's diagnosis, patient classification by NCMRR disability scale, results of the history and physical exam, patient demographics, gait studies done, anthropometric parameters used in the analyses, results of the analysis, treatment recommendations, treatments performed, and treatment outcomes. Determine exactly what items within these categories to include and set standards for data collection, input, and access for the database. Estimate necessary computer and personnel resources and provide necessary support. Advertise database development and enlist cooperation among existing laboratories. Develop rules for inputting, sharing and utilizing the data. Determine rules for handling outside requests for database access.

Recommended Actions

The NIH should establish the database at its biomechanics laboratory.

Recommendation Title: Standards for Reporting the Results of Clinical Gait Analysis

Recommendation Code: B5

Category: Standardization

Recommendation

Background

There are multiple opportunities for standardization in the reporting of gait analyses. Differences in the reporting of gait studies typically fall into one of two formats depending on the preference of the lab. For example, this can result in graphs of angular joint kinematics going in opposite directions or joint moments being reported as external or internal. There are also a multiple systems of terminology for describing parts of the gait cycle and other parameters. This situation causes needless confusing during the training and education of students and colleagues and complicates data sharing among laboratories. Increased uniformity of reporting gait analysis would streamline the education of students and technicians, facilitate sharing of data among laboratories, and in the long run, reduce confusion during the interpretation of results. In the long-term, more intuitive, user-friendly ways of reporting the results utilizing three-dimensional graphical displays, etc., would improve our ability to communicate the results with colleagues and users of our services.

Objectives

1) Members of the clinical gait analysis community will develop a standardized reporting format for the results of gait analysis.

2) Priorities for standardization: terminology, internal vs. external moments, orientation and units of measurement for graphical displays, procedures for normalization.

3) The mechanism for selecting the standards will be fair and engender a spirit of cooperation.

Recommended Actions

1) Publish position papers from two invited experts with opposing viewpoints on controversial issues in Gait and Posture, with commentary in subsequent issues.

2) Poll the clinicians providing or regularly utilizing the services of gait laboratories to select standards. Include a copy of the printed debates and commentary from Gait and Posture along with the ballot.

Recommendation Title: Collaboration via Telecommunications / Telemedicine

Recommendation Code: B6

Category: Resources and Collaboration

Recommendation

Background

Individual gait laboratories have their areas of special expertise. If gait laboratories could quickly and inexpensively share information, collaboration and consultation would be facilitated and recommendations could be improved. This could be especially beneficial for newly developing laboratories and facilitate the rapid development of local expertise as gait laboratories expand into underserved areas. Although this raises difficult legal and ethical questions concerning practice across state lines and without actual clinician-patient contact, the potential benefits warrant the exploration of this technology.

Objectives

1) Study the CAMARC system and use the experience of our European colleagues in establishing the North American System.

2) Take advantage of technology typically existing in gait laboratories (video cameras, computers with frame grabbers, etc.) and integrate them into the system design wherever possible.

3) Study the legal and ethical issues to ensure appropriate and defensible utilization of the resource.

Recommended Actions

Demonstration project grant funding for this capability should be a federal funding priority.

Recommendation Title: Improved Sensors of Neuromusculoskeletal Activity in Gait Analysis

Recommendation Code: B7

Category: Technical Development / Research

Recommendation

Background

Subdermal EMG and pressure measurements are valuable tools of gait analysis, but difficult, expensive and painful to utilize. Non-invasive sensors of neural signals, muscle and ligament forces and bone stresses would be of great value to modeling and gait analysis. Means to extract such data from deep structures are not known today. However, opportunities to innovate such sensors may be offered by X-ray CT MRI, PET, ultrasound, radioactive tracers and microtransducers or magnetic or specific-chemicals-sensitive particles parentrally injected into the vascular system.

Objectives

1) Identify, research and qualify non-invasive sensors for gait analysis.

2) Remove sufficient risk so that private manufactures will develop robust and cost-effective products.

Recommended Actions

Support research on non-invasive sensors to measure the variables of gait.

Recommendation Title: Automated Protocol for Determining Joint Centers

Recommendation Code: B8

Category: Technical Development / Assessment

Recommendation

Background

Currently available software that uses a passive or active marker system to determine the joint center has many problems in clinical use.

For example, the movement of the skin on which the marker is attached over the bony landmarks makes the joint center determined by software not match the true joint center and vary from time to time during the gait cycle. If the marker position from serial studies (e.g., preoperative and postoperative) differ, the data from serial studies can not be compared. Also, the data from studies utilizing different software can not be compared because the protocols to determine joint centers differ.

Objectives

Develop an automated method and protocol for determining joint centers regardless of the position of the surface markers (i.e., a small difference of marker position does not affect joint center determination).

1) Create a “gold standard.”

2) Develop uniformly acceptable software and marker placement protocol.

Recommended Actions

Government agencies and commercial organization support research to achieve objects.

Recommendation Title: Identify the Relationship Between Impairments, Functional Gait Limitations, and Disability

Recommendation Code: B9

Category: Research

Recommendation

Background

A causal relationship between specific physical impairments, functional gait limitations, and disability has not been well established. Rehabilitation treatment plans often focus on physical impairments (e.g., weakness, contracture, spasticity) with the hope that minimizing impairments will minimize disability. In cases where impairments cannot be changed, rehabilitation teaches compensatory strategies for existing impairments to minimize functional limitation and disability. Through gait analysis, thresholds for levels of impairment could be identified that predict a greater likelihood of disability and provide clinicians with objective information from which to develop goals with their clients and prioritize treatment plans. It is likely that the relationships between impairment, functional gait limitation and disability are patient population-specific. Additionally, in the case of chronic progressive disorders with increasing severity and number of impairments over time, these thresholds could help to identify critical periods when rehabilitation intervention is essential to maintain ambulation ability.

Objectives

1) Determine the relationships between impairments, functional gait limitations, and disability.

2) Determine optimal treatment strategies via outcome studies to reduce the impairments or compensate for those impairments that cannot be changed.

Recommended Actions

Funding agencies should support research...

1) That includes measures of impairments, functional limitations, and disability and their interrelationship.

2) That utilizes direct experimentation or computer modeling and simulation.

3) That develops biomechanical and neural models that predict the relationship between impairments, functional gait limitations, and disability.

4) That assesses the efficacy of the application of existing treatment methods and development of new treatment methods based on these conceptual models.

Recommendation Title: Toward Routine Utilization of Gait Analysis

Recommendation Code: B10

Category: Technical Development

Recommendation

Background

Gait analysis is under appreciated by health care professionals, health care payers (managed care), and the community at-large. One reason is that gait labs require large space, multiple personnel, and high-cost equipment that prohibits its accessibility and utilization. Secondly, gait data is voluminous and its presentation so complex to be incomprehensible to most health care professionals and the community in general. A third reason is the limited availability of software to simulate locomotion that is useful to gait assessment and treatment. Cutting edge hardware (e.g., insole force measurements, advanced treadmills, laser imaging) has the potential to simplify and compact the gait lab. State of the art animation (e.g., Kaufman, herein) and simulation (e.g., Zajac, herein) software technology can improve the assessment and treatment of gait disorders.

Because the gait lab community is relatively small, the availability of private capital to facilitate the diffusion of this technology to end users is limited.

Objectives

To optimize gait data acquisition, processing, interpretation, and presentation in order to improve utilization by healthcare professionals and appreciation by the public.

Specifically, this would include:

1) Development of user-friendly software for healthcare professionals that can be utilized to analyze, design, and validate patient-specific gait outcomes.

2) Development of data presentation software, including animation technology, which can be readily understood by both members and nonmembers of the gait community.

3) Development of a low cost, dependable, easily operated, mobile, gait analysis system that can produce accurate output for both clinical and nonmedical utilization in the community.

4) Promotion of the awareness of the utility of gait analysis amongst healthcare professionals and the community at large.

Recommended Actions

Interagency funding sources need to be designated and private sector participation sought.

Recommendation Title: Educate Clinicians in the Use of Gait Analysis in Treatment Planning and Implementation

Recommendation Code: B11

Category: Education

Recommendation

Background

The appropriate application of gait analysis can have a significant impact on the lives of people with disabilities. A major barrier to optimal referral and utilization of results in treatment planning and implementation is the lack of a basic understanding by physicians, therapists and orthotists/ prosthetists regarding its capabilities, benefits and limitations. Despite mounting evidence that gait analysis can provide valuable information in directing interventions such as surgery, it is not widely utilized.

Objectives

To improve the appropriate utilization of gait analysis in treatment planning through education based on scientific evidence.

Recommended Actions

1) Professional organizations such as the North American Society of Gait and Clinical Movement Analysis should provide funding for instructional courses targeted at relevant professional disciplines.

2) Government and industry should provide funding to develop educational tools which utilize easily understood representations of the data obtained from gait analysis.

3) Government and private training grants or other sources should fund fellowships for clinicians in gait analysis facilities.

4) Accreditation agencies of appropriate professional groups should require inclusion of gait analysis material in professional education curricula.

Recommendation Title: Effectiveness of Gait Analysis

Recommendation code: B12

Category: Research

Recommendation

Background

There is limited evidence to suggest that the results of gait analysis can be used to guide rehabilitation treatment planning and improve walking ability of people with functional gait limitations and disabilities. However, the contribution of gait analysis to the rehabilitation process and its potential benefit has not been systematically documented in an adequate number of research studies. Treatment decisions may be improved by more complete objective information provided by gait analysis, and may result in more effective and efficient interventions.

Objectives

Conduct research aimed at determining whether the use of gait analysis influences treatment decisions, improves treatment outcomes, and reduces the cost of treatment.

Recommended Actions

1) Granting institutions should provide funding to conduct research that determines if gait analysis improves the ability of clinicians to classify patients into appropriate treatment groups.

2) Granting institutions should provide funding to conduct controlled randomized research studies to document the impact of gait analysis on treatment and outcome.

Recommendation Title: Advance Research Evidence for the Clinical Utility of Movement Analysis Across a Broad Range of Pathophysiologies

Recommendation Code: C1

Category: Research

Recommendation

Background

Movement analysis has been proven a useful tool for evaluating functional limitations. Most of the existing literature has focused on the application of gait analysis in pediatric patients with cerebral palsy. Movement analysis can quantify functional limitations associated with a variety of impairments. For example, three dimensional kinematic and kinetic evaluations have the potential to identify motor patterns and strategies of an individual and compare that profile to normative data, or identify primary problems versus adaptive mechanisms. Combining this information with electromyographic data can allow one to distinguish spasticity from weakness and provide information regarding agonist and antagonist muscle synergistic patterns.

While the benefit of identifying and quantifying specific movement impairments have been demonstrated in the cerebral palsy population, there exists potential in other areas that have not been addressed such as; spina bifida, amputees, stroke, spinal cord injury, arthritis, low back pain, arthrogryposis, post polio syndrome, Multiple Sclerosis, etc. It would be desirable to develop biomechanical models and testing guidelines which would lead to protocols to measure functional limitations specific to these pathophysiologies.

Objectives

To increase the specificity of movement analysis in a variety of pathophysiologies.

Recommended Actions

Funding from NIH and other agencies such as, Department of Defense, Muscular Dystrophy Association, and the Veterans Administration, in the form of RFAs for research applying movement analysis to a variety of functional limitations in various pathological conditions.

Recommendation Title: Scope and Availability of Gait Analysis Facilities

Recommendation Code: C2

Category: Policy / Training

Recommendation

Background

Clinical gait analysis has established a strong beachhead particularly in hospitals that serve children, especially children diagnosed with cerebral palsy. It is now important to make a breakout so that gait analysis techniques and knowledge can be applied to a wide spectrum of movement pathologies and to a wide-range of patients. Until movement analysis facilities are placed in rehabilitation hospitals and general hospitals on a wider basis, people with locomotion disabilities may be prevented from receiving movement and pathokinesiological services. These laboratories or departments should not be focused on particular instruments or pathologies but should provide needed services appropriate to the patient referral base. Services might go beyond gait analysis to encompass more generally movement analysis.

Objectives

The objective is to make clinical movement analysis services much more widely available and more generally applied in medical care facilities. More specifically:

1) Facilitate the access of movement analysis labs to clinicians. Foster partnerships between clinicians and people in academia engaged in movement science.

2) Examine and evaluate working models of the application of movement science in general medical practice.

3) Open up access to existing movement analysis labs to practicing clinicians. Encourage publication of case studies using movement analysis techniques to assist in clinical decision making.

Recommended Actions

1) Fund clinical scholars programs to bring clinicians into research facilities that perform movement analysis. Additionally, fund research fellows and faculty from centers of excellence to train staff in clinical facilities while gaining appreciation of clinical issues.

2) Fund a study of the efficacy of open access European and Canadian clinical movement analysis labs associated with hospitals.

3) Peer reviewed journals, particularly Gait and Posture, should publish case studies and compilations of cases which use movement analysis data.

Recommendation Title: Establish Comprehensive Gait Analysis (GA) as a Standard of Care in Pre-Surgical Decisions for Ambulatory Children with Cerebral Palsy (CP)

Recommendation Code: C3

Category: Policy

Recommendation

Background

The traditional treatment for children with diplegic and hemiplegic pattern CP consisted of multi-staged surgical procedures. Complex GA consisting of 3D kinematics, electromyography, and kinetic analysis has produced more specific information leading to directed surgeries. Numerous published studies have demonstrated that patients who have undergone such comprehensive GA have had fewer surgical procedures and have demonstrated improved outcomes. Despite these demonstrated clinical improvements, the majority of children with CP continue to undergo surgery without the benefit of pre-operative GA.

Objectives

Establish comprehensive GA as a part of the standard of care for ambulatory children with CP prior to surgery.

Recommended Actions

Several actions be taken regarding the following statement:

Pre-surgical decisions for ambulatory children with CP should be based, in part, on data acquired in a comprehensive GA carried out in a laboratory with demonstrated ability to collect and interpret 3D kinematic, kinetic, and EMG data in children with complex movement disorders.

1) Gain consensus regarding this statement at meeting on Gait Analysis in Rehabilitation Medicine sponsored by NCMRR, Sept. 26-28, 1996, Arlington, VA.

2) NCMRR endorse this statement.

3) To gain wider acceptance for this statement, established authorities in this area (e.g., Jim Gage, Jacqueline Perry, David Sutherland, etc.) need to generate a consensus statement supporting the above position at a national forum such as the annual meeting of the North American Society of Gait and Clinical Movement Analysis (NASGMA).

4) Accepted authorities will publish this statement with appropriate supporting documentation in peer-reviewed journals and disseminate it at appropriate meetings such as NASGMA and the American Academy for Cerebral Palsy and Developmental Medicine (AACPDM) and interested consumer groups.

Recommendation Title: Role of Three-Dimensional Computerized Gait Analysis in Treatment Decision-Making and as an Outcome Measure and its Cost Effectiveness

Recommendation Code: C4

Category: Limited Access/Outcomes

Recommendation

Background

A major barrier to the clinical implementation of gait analysis technologies in some surgical and most rehabilitation settings, and therefore access to these technologies, is the paucity of quantitative research documenting the advantage of computerized gait analysis over traditional clinical evaluations (static physical examination and observational gait analysis) in treatment decision-making, outcome assessments, and cost- effectiveness. Historically, most orthopaedic surgeons and rehabilitation specialists have relied primarily on static examination and observational gait analysis to make treatment decisions. Single level surgeries and other ineffective treatment strategies may have resulted from these diagnostic approaches. Treatment outcomes have either not been performed or have relied on more qualitative methods, that are not as valid or reliable. Furthermore, the costs of ineffective treatments and staged single level surgeries have not been closely scrutinized. Computerized gait analysis can provide valid, reliable, and quantitative information, but it has not been demonstrated to be a superior tool in well controlled studies.

Objectives

Test the hypothesis that three-dimensional gait analysis is:

1) Superior to traditional methods of evaluation used by surgeons and rehabilitation specialists in treatment decision-making for specific diagnoses.

2) It can provide superior quantitative outcome measures of treatment.

3) It is cost effective.

Recommended Actions

Provide funding to centers of excellence to design well controlled studies to:

1) Compare the effectiveness of computerized gait analysis to traditional methods of evaluation used for locomotion impairments in treatment decision making.

2) Study the outcomes of treatments of locomotion impairments using computerized gait analysis in order to determine the most appropriate gait measures to be used as outcome measures.

3) Study the cost effectiveness of utilizing computerized gait analysis as an evaluation and outcome measure tool.

Recommendation Title: Time/Distance Analysis for Use in Group/Multicenter Outcome Studies

Recommendation Code: C5

Category: Research/Outcome/Limited Access

Recommendation

Background

A major barrier to gait analysis in large clinical trials is the expense of a complex study. Functional measures of ambulation/ mobility however are often lacking in precision to capture the benefit from improvements in strength and stability due to the use of a specific intervention such as drugs, exercise etc. A low cost, reliable measure of walking is a time/distance analysis which includes gait velocity, cadence, step and stride length, base of support, time in single and double support, percentage stance, and percentage swing.

Objectives

Establish norms for time/distance analysis for specific groups of impairments as a simple, reliable, quantitative and low cost test of walking.

Recommended Actions

Develop studies on group of impairments/diseases in which drugs, exercises and other interventions are shown to have a superior outcome for walking by time/distance analysis.

Recommendation Title: Define the Components of Gait Analysis.

Recommendation Code: C6

Category: Access/Utilization Barriers

Recommendation

Background

The vast majority of patients with impaired locomotion are effectively denied access to objective locomotion analysis, even in it's most rudimentary form. These patients are only assessed visually by clinicians, who must then make decisions about treatment or outcome based on this impression. It may be that this has no real consequence on the outcome, for example, an athlete presenting with an antalgic gait pattern resulting from a sprained ankle, will almost certainly not undergo a course of treatment or attain an outcome that would be any different even had a locomotion analysis been performed. Here a subjective assessment would be sufficient. At the other extreme a negative outcome may result if a comprehensive locomotion analysis is not done before a multilevel surgical procedure is undertaken on a patient with cerebral palsy, for example. Between these two extremes are patients that could benefit from having their walking pattern analyzed in some objective manner but who probably do not need a comprehensive, highly sophisticated and expensive analysis. As an example, the patient with diabetic neuropathy would benefit from an analysis of the distribution of forces under the foot either as a diagnostic procedure or as an outcome measure. There is a need therefore to clearly define objective locomotion measurements, the technologies used to obtain them and an indication of their implementation in clinical-decision making. This would result in a list of the components used in clinical locomotion analysis together with codes to identify them. From this list could be selected one or more measurements which would best meet the needs of a given patient. This selection would be helped by the provision of clinical indications, including clinical practice guidelines for the most effective use of these measurements and technologies. The use of the codes should be used by clinical facilities to clearly define the level of locomotion analysis that they have used thereby maintaining the integrity of the term Locomotion Analysis.

Objectives

1) Develop a list of objective locomotion analysis measurements and technologies and assign codes to them.

2) Determine under what conditions and for what purposes these measurements and technologies should be used.

Recommended Actions

Provide funds to:

1) Develop a list of locomotor measurements and technologies (a sample list of these is attached) and assign to these identification codes such as CPT codes.

2) Develop guidelines for clinicians that indicate the technologies and measurements most appropriate for given pathologies, impairments or functional limitations.

Recommendation Title: The Development of Interactive Software to Assist Professionals in the Interpretation, Synthesis and Use of Locomotion Data.

Recommendation Code: C7

Category: Technology Development

Recommendation

Background

A barrier which prevents people with locomotion disabilities from accessing gait analysis relates to the difficulties which many professionals have in understanding the data. New and emerging technologies provide the power to present and share complex data sets in more clinically relevant ways. These technologies exist and now need to be synthesized into a meaningful software package.

Objectives

1) Create a system which will enhance the presentation of gait analysis data and assist the practitioner in the interpretation and use of these data.

2) Design a system or package which will integrate chart information, expert systems and linguistic phrases, interactive graphics, and predictive simulations. This system will take advantage of emerging technologies for transparent data transfer, confidentiality and access to established data bases.

It is anticipated that these objectives will be addressed by developing:

> a) Charting procedures for presenting summary results of objective gait analysis in a form which practitioners find useful and which compliments existing subjective reporting procedures.
>
> b) Interactive graphics systems to assist the professional in the understanding and interpretation of motion analysis data.
>
> c) Expert systems to assist the professional in the decision-making questions which arise from the gait analysis data and which can be utilized to capture interesting data which does not meet a priori expectations.
>
> d) Predictive simulation models that can answer the what if question.

Recommended Actions

1) Convene a workshop to reach consensus among gait experts and interested professionals on:
the process by which experts currently interpret, synthesize and utilize data in clinical decision-making, prioritizing the development of interactive software to assist clinicians in the interpretation, synthesis and use of locomotion data.

2) Put out an RFA to implement the recommendations of the workshop. This RFA should emphasize collaboration and cooperation between disciplines and centers involved in motion analysis.

3) Host a second workshop to establish testing and implementation procedures, to provide training for the new software package, and prioritize areas for subsequent development.

Recommendation Title: Standardization of Gait Analysis

Recommendation Code: C8

Category: Policy

Recommendation

Background

Lack of standards are a critical factor limiting access to gait analysis by people with locomotion disabilities. For example, a physician may not refer a patient for a gait analysis study because of a lack of understanding of how the evaluation could improve treatment and document outcome. Standards are needed to facilitate sharing of clinical and research data, for ensuring the quality of services provided, for education of and communication between various health care providers and consumers, and for improving reimbursement. Standards will also enhance interfaces between rehabilitation technologies, facilitate the inclusion of technological innovation outside of rehabilitation medicine, and encourage communication with common biomechanical parameters. Standards will allow all pertinent stakeholders, including physicians, other healthcare providers, third party payers and consumers, to be educated about the indications for a gait analysis study and what is provided as part of a gait analysis evaluation. Standards will also allow these individuals to be consistently educated so the results of the gait analysis study are meaningful to them and the value of gait analysis is understood. Standards will facilitate multicenter research studies to document the impact of gait analysis in rehab medicine and to establish a consensus of outcome measures. Standards will also allow transparent exchange of information using advanced telecommunication and computer technologies.

Objectives

Establish standards to ensure consistency in the provision of clinical services and information exchange, and facilitate multicenter research.

Recommended Actions

The NASGCMA should take the lead in a proactive process directed toward establishing comprehensive voluntary standards that address the needs discussed above. This process should include the following stakeholders: members of the NASGCMA standards committee, government (FDA and NIH), the AMA, the APTA, the ISB standards committee, the disabled community, the information technology industry and the equipment manufacturers. The process of establishing standards will require workshops that bring together these stakeholders. Funding will need to be identified to effectively carry out these workshops.

Recommendation Title: Accreditation of Diagnostic Clinical Gait Laboratories

Recommendation Code: C9

Category: Standardization

Recommendation

Background

Individuals with locomotion disabilities and their third party payers have difficulty determining which gait laboratory is appropriate to evaluate their specific disability. There currently are a large number of different types of equipment ranging from simple home video cameras to very expensive multiple time synchronized camera systems to evaluate three dimensional kinematics and kinetics. Gait laboratories are also operated by many different individuals with different levels of training and backgrounds. Many of these diverse laboratories claim to do diagnostic analysis, however they provide very different levels of useful information. This large diversity of clinical gait laboratories makes it difficult for individuals and insurance companies to evaluate what is being done and how it positively contributes to the individuals care. This confusion leads to individuals not obtaining appropriate studies because they nor their third party payers can be sure that the laboratory data will be valid and useful. Further more there are studies being performed in laboratories where the data is probably of marginal use. Impairment and diagnosis specific evaluations also vary widely leading to decreased cost- effectiveness through over and under utilization of specific elements of the analysis.

Objectives

To make available clinically useful gait analysis to individuals with locomotion disabilities in a cost effective manner. Use a multidisciplinary approach to define algorithms, methods, and appropriate personnel to provide useful clinical information in assisting in planning treatment of individuals with disabilities.

Recommended Actions

The gait laboratory community should establish a process for individual laboratory accreditation. This accreditation should consider the impairment and diagnosis to be tested, appropriate techniques to be used, and the level of sophistication appropriated to the individual to be tested. The training and competence of personnel staffing gait laboratories should be considered as part of this accreditation. This process should be coordinated with a standardization process.

Recommendation Title: Medical Education Models for Health Care Professionals

Recommendation Code: C10

Category: Education

Recommendation

Background

The fact that health care professionals have a lack of knowledge and education regarding the scope and clinical relevancy of gait analysis is a major barrier that prevents people with locomotion disabilities from accessing gait analysis. Gait analysis provides the technology that can measure, describe, quantify, and identify movement deviations and functional limitations. When interpreted by a skilled individual, gait analysis can provide additional clinically relevant information that is not available by any other method. This information can mean the difference between successful outcome and poor result. Despite this, as a measurement tool it is under used and not widely accepted for treatment planning. Just as x-ray is one of the definitive diagnostic procedures in the treatment of fractures, so gait analysis should be one of the definitive procedures for the assessment and treatment of locomotor disability and treatment planning. In current professional instruction and training programs locomotor disabilities are neither understood nor taught.

Objectives

1) Institute a change in professional education of health care professionals in the area of gait analysis.

2) Promote the use of gait analysis in the diagnosis and treatment of locomotor disabilities.

3) Improving interprofessional understanding of gait analysis as a clinical tool.

4) Promote the idea of an intradisciplinary team for gait analysis interpretation in an attempt to improve clinical usefulness.

5) Advocate for "centers of excellence" in the treatment of complex gait disorders.

Recommended Actions

1) Through an appropriate Board, accredit regional "centers of excellence" which will train professionals and treat of complex neuromuscular disorders.

2) Provide funding to the "centers of excellence" for the development of programs which train health care educators so that the principles of normal locomotion and motion analysis are incorporated in the basic science curriculum.

3) Government agencies will mandate the incorporation basic science training in math and engineering into the residency or professional programs of health disciplines which treat locomotor disorders.

4) Government agencies will mandate the incorporation of training in both gait analysis and the principles of normal and pathological gait into residency or professional programs of health disciplines which treat locomotor disorders.

5) Develop fellowship training programs at "centers of excellence" which will provide training in both gait analysis and the principles of normal and pathological gait to health disciplines which treat locomotor disabilities.

6) Provide funding to develop educational materials in the field of gait and gait analysis which could include electronic media, CD-ROMs, internet websites, etc.

Recommendation Title: Consumer and Patient Education

Recommendation Code: C11

Category: Education

Recommendation

Background

Because consumers are not widely aware of the availability of locomotor analysis, consumers do not routinely advocate for referral to locomotor centers of excellence. If parents were made aware that their children's surgical outcome might be improved by preoperative gait analysis, physicians and third party care payers would more frequently refer these children. Similarly, if persons with locomotor disabilities were aware of the benefits conferred by locomotion analysis, they would stimulate demand for high quality, objective locomotion analysis. By analogy, people with migraine headache request referral for MRI to attempt to determine the headache cause. The popular media, including newspaper articles, NOVA and other TV shows, routinely feature MRI and other "high tech" medical investigations for common problems. Articles in consumer magazines such as Abilities Unlimited, Accent on Living, Paraplegia News, Exception Parent and others might reach consumers directly if the material were written in consumer-oriented language. If the gait analysis community were to obtain similar media coverage, the public would be better informed and better served by locomotion analysis. World wide web sites, information provided to, eg, local UCP, MDA, Easter Seals and PVA branches, schools and stroke clubs are other venues for information dissemination. Centers of excellence would educate consumers, and stimulate consumer demand, by word of mouth.

The New England Journal of Medicine, Journal of the American Medical Association, and other leading medical journals frequently inform the popular press about medical discoveries. Physicians must then read the journal to intelligently answer their patients' questions about the "news." A similar approach from gait related professional journals would better inform the public, and, not incidently, increase demand for these publications among care providers.

Objectives

Increase public awareness of and demand for high quality locomotor analysis.

Recommended Actions

Provide funding mechanisms that stimulate the development and dissemination of locomotion related material to the popular media, parents, and local consumer organizations. North American Society of Gait and Clinical Movement Analysis and other interested societies should provide to consumer groups pamphlets describing the benefits, locations and advantages of locomotor analysis.

Encourage professional journal editors to provide to the popular press breaking news about locomotion research and clinical applications.

Recommendation Title: Universal Access to Gait Analysis Services

Recommendation Code: C12

Category: Policy/ Research

Recommendation

Background

In the current managed care market place, individuals with locomotor disabilities have limited access to gait analysis because of policy and lack of payment. Access is denied by managed care organizations that restrict access based on artificial geographic boundaries and who restrict care to network providers. Gait analysis is often denied by third party payers and managed care organizations as an experimental procedure which is not cost-effective. Individuals without expertise are dictating which services are necessary or not necessary for treatment. Rather than resulting in decreased cost, this situation results in increased costs and/or suboptimal outcomes because of unnecessary and inappropriate treatments. Centers of excellence should be identified and individuals have the right to care at these centers to maximize their function in society.

Objectives

1) Institute a change in the health care delivery system to assure that patients with locomotor disabilities have access to gait analysis services.

Recommended Actions

1) The field of gait analysis should promote legislation that mandates third party payers and managed care organizations to provide individuals with locomotor disabilities access to care at accredited laboratories and/or centers of excellence with gait analysis.

2) The field of gait analysis should promote legislation to prohibit third party payers from being the gatekeeper of the care of individuals with locomotor disabilities, and promote the use of centers of excellence to be the gatekeepers of their care.

3) Funding for research should be made available in the area of gait analysis which illustrates the cost-effectiveness of its use as a tool that optimizes care.

4) Promote research and provide funding for outcome studies which illustrates the efficacy of gait analysis.

5) Appoint a task force made up of individuals from multiple disciplines/agencies to investigate and determine the regional clinical centers of excellence for specific movement disabilities that all third party payers in that region use for treatment. Promote the concept that all centers of excellence for locomotor disorders should be associated with an accredited gait laboratory.

Recommendation Title: The Development of Information Resources Which Will Help New Gait Laboratories to Develop Successfully

Recommendation Code: C 13

Category: Education

Recommendation

Background

One of the major limitations in the access to gait analysis by individuals with locomotion disabilities is the limited number of clinical laboratories. Establishing laboratories requires appropriate equipment, space, personnel and referral base. Administrative decisions to built new laboratories are often made without thorough consideration of all these issues. Some, or all of these needs are may be over looked by administrators. Manufactures have at times been more interested in selling equipment than developing successful functional laboratories.

Objectives

To provide complete and accurate information to facilities who are interested in building new laboratories. Allow potential laboratories to make informed decisions about their function and decrease the incidence of failure.

Recommended Actions

1) Equipment vendors work with the North American Society of Gait and Clinical Movement Analysis (NASGCMA) to develop information concerning all aspects of the basic operation requirements of a clinical gait laboratory. We encourage vendors to provide this information to administrators interested in developing new laboratories.

2) Identify and refer volunteers from the NASGCMA who would be willing to serve as consultants to new laboratories.

Appendix A:

Alphabetical Listing of Participant Personal Statements on Gait Analysis in Rehabilitation Medicine

Mark F. Abel, M.D.

The major reasons why clinicians have questioned the utility of motion analysis is that it requires the acquisition of new knowledge related to gait mechanics. When the MRI was introduced for musculoskeletal imaging, clinicians were resistant to learn the technology because it did not offer anything over CT scans. However, it is now been accepted as a vital part of diagnostic imaging. Similarly, with motion analysis, a new technology must be learned. Although many people take care of children with cerebral palsy, only a minority understand how to read gait data. However, I feel it is an important part of following the progress of people that have neuromuscular conditions. Establishment of a standard format and education of clinicians is clearly needed.

Another glaring problem which undermines the use of these laboratories is that validity of the instruments has not been clearly established. Multiple variables including temporal, kinematic, and kinetic can be measured and we are only beginning to appreciate the variability of these measures.

In summary, gait laboratories should have an important role in both basic and clinical medicine. Once the reliability of the measures have been established, characterization of clinical conditions affecting motor control and following progress of these conditions should be possible and best achieved using motion analysis. Collaboration between laboratories, I believe, is extremely important not only to answer the questions of variability but also to expand into the arena of outcome assessment.

Gordon J. Alderink, MS, P.T.

The Center for Human Kinetic Studies (CHKS) was established through the joint efforts of Grand Valley State University and Mary Free Bed Hospital & Rehabilitation center in 1992. The primary objective of the lab is to provide a service to the orthopedic and rehabilitation physicians in Western and Northern Michigan to aid in their treatment decision processes by providing objective, reliable data related to gait and other movement dysfunctions. The CHKS is also committed to clinical research, which is carried out by lab staff and Grand Valley State University physical therapy faculty and graduate students. Our staff have been involved with the clinical motion analysis community by attending nationally held clinical gait conferences, staying abreast of the many critical issues that are impacting clinical motion analysis, and by being involved in activities related to standardization of motion analysis laboratories. We are pleased with our development to this point, but are concerned about several issues, including: 1) Reimbursement and lack of specific CPT or other payment codes for computerized gait analysis (CGA); 2) Inadequate understanding of how CGA can or should be used by rehabilitation specialists; 3) Under utilization by orthopaedists and rehabilitation specialists (both physicians and therapists); 4) Lack of universal acceptance of CGA as a valid and reliable clinical tool (many insurance companies consider CGA as experimental or research); and 5) How CGA may be utilized in an environment increasingly dominated by managed care.

Through the insight and work of Simon, Sutherland, Perry, and Gage (and many others) CGA has been used for clinical decision-making for approximately 20 years. As a result CGA has become the standard of care where it is available. CGA has made it possible for clinicians to make more precise treatment decisions (with more confidence) and measure their outcomes accurately and reliably. Outcome studies using CGA have made it possible for surgeons to improve their treatment decisions. For example, rectus femoris lengthening for the child with spastic diplegia has been replaced by a transfer technique, partly because of the information that CGA was able to provide. Although the orthopaedists have benefited from CGA, it seems that rehabilitation specialists have not taken advantage of this technology for the treatment of stroke, traumatic brain injury and amputation. CGA has had a major impact in the management of certain patients and has been shown to be cost effective, reliable and objective, but there are several issues that need to be addressed: 1) With the proliferation of new motion analysis laboratories standardized procedures need to be established; with standardized procedures the consistency of data will be improved and payers will more likely accept CGA as standard care (not experimental); 2) Rehabilitation specialists (physicians and physical therapists) and payers (private and public need to be educated on the benefits of CGA; 3) Specific CPT codes need to be established for CGA; and 4) An accreditation process for motion analysis laboratories would also help insure quality of care.

Because CGA is not readily available to everyone, observational gait analysis becomes a very important clinical tool. This tool has been used by rehabilitation specialists for many years. It is convenient, very cost effective and available to all. However, it may not be as valid or reliable as CGA. I do not believe that this tool is being used consistently and with standardized procedures by those in rehabilitation medicine. At the CHKS we use observational gait analysis in conjunction with CGA and have adopted the terminology and procedures established by J. Perry and Ranchos Los Amigos. I believe that their operational definitions and procedures are precise and easy to apply. Recently, researchers at Rancho studied and reported on the validity of objective observational gait analysis, using CGA as the standard for comparison. Their results were reasonably good. Since observational gait analysis will probably not be replaced by CGA I believe that better standardization of those procedures need to be established.

Recommendations:

1) Educate the rehabilitation community on the utilization of CGA.
2) Establish standards of care regarding the use of CGA.
3) Educate payors (private or public) on the use of CGA.
4) Establish payment codes that are specific to CGA.
5) Examine how CGA will be utilized in a management care environment, where cost containment and efficacy will be the goals.
6) Continue basic and clinical research using computerized biomechanical analysis to analyze how it can be used to cost effectively enhance the practice of orthopaedic and rehabilitation specialists.
7) Establish the validity and reliability of observational gait analysis and standardize those procedures to enhance the clinical practice of those who do not have CGA.

Sherry I. Backus, M.A., P.T.

Gait analysis has increased not only in the scope of the types of patient being referred for gait analyses, but also in the availability of the technology to perform these tests and the nature of the inferences/recommendations being drawn from these tests. There are several issues related to each of those three areas that need to be addressed to ensure consistent quality care is being provided to people with disabilities.

1. **Increased outcomes research.** There has been a greater emphasis in all areas of rehabilitation to facilitate outcomes based research. This shift has only just begun to occur in the gait analysis literature. The majority of the literature that relates gait analysis to outcomes research is in the CP patient population, and even in this population, there are gains to be made. In addition, there are few outcome studies in other patient population groups. The effectiveness and justification of this costly evaluative technique must be determining and quantifying the pre-operative/pre-treatment characteristics (kinematics, kinetics) that influence post-operative/post-treatment function and outcomes. It is not simply sufficient to document an increase in knee flexion angle by 20 degrees, the functional benefits need to be documented also.
2. **Expanded applicability to a variety of disabilities.** The use of gait analysis in the CP patient population forms the basis for many clinical and research gait laboratories. However, the role of clinical gait analysis in persons with other neurologic, orthopaedic and balance dysfunctions is poorly documented. Certainly gait abnormalities have been described in a variety of conditions, but the practical implications and ramifications for treatment and surgical selection have not been documented. While this relates in part to outcomes research, it also relates to a lack of knowledge of how the information gained from gait analysis can be applied to recommendations and treatment suggestions. The usefulness of gait analysis in the clinical setting needs to be better communicated to a side variety of health professionals and patients. In addition, the limitations of gait analysis need to be understood so that appropriate referrals are made. X-rays are an inefficient way to determine knee ligament instability, and similarly, gait analysis may not be a cost effective evaluative tool for every diagnosis; these limitations need to be better understood.
3. **Standardization.** This has been a topic of sub-committees, task forces, vendors, and across many institutions. These discussions have highlighted the difficulties in standardization of measurement techniques, testing protocols, terminology, and reporting formats to name a few areas. The implications for clinical gait analysis are apparent as testing services may be provided at one institution for a physician/clinician in another institution. The challenge is to allow not only multi-center research studies, but also interpretation of clinical data that is not institution specific.

In order to advance gait analysis in rehabilitation medicine, the following are recommended:

1. Development and funding for outcomes research across a variety of disabilities.

2. Increased awareness to health care providers, third party payers, and patients as to the benefits and limitations of gait and functional movement analysis. As providers, we must be as cost aware as are the patients and payers, and as providers, we must continue to document that those unique measurements made during gait analysis have some meaningful relationship to treatment options and prognosis.

3. Continued improvements in standardization across testing institutions.

4. Inclusion of all facilities providing gait and functional movement analyses in these processes. As the amount of local expertise and technology in a facility is varied, and the locations ("gait laboratories," out-patient settings, private practitioners offices, etc.) where gait analyses are performed expand, communication of advances and standards need to be widely disseminated.

Claire C. Bassile, Ed.D., P.T.

The research community is keenly aware of the 'potential' impact that gait analysis information can have on the treatment intervention for individuals with disability. This relationship has been established for determining the orthopedic surgical procedures in children with cerebral palsy. The application of gait analysis in identification of impairment(s) as well as influencing nonsurgical treatment interventions (i.e., physical therapy) in other clinical populations has not been investigated thoroughly. Lastly, the literature that is available on these issues has not been widely disseminated to the health professionals which rehabilitate individuals with gait impairments. Therefore, I would urge federal funds be allocated for studies which:

1. Target a variety of clinical populations and identify the relationship of impairment(s) to functional limitation in gait.

2. Utilize gait analysis information in the development of treatment implications for clinical populations.

3. Seek to document the efficacy of a particular treatment intervention through the use of gait analysis and identifies at what level (pathology, impairment, functional outcome) the improvement is occurring.

4. Identify gait analysis tool(s) or methodology(ies) which provide the most appropriate/sensitive measures for the clinical populations investigated.

5. Identify the appropriate/sensitive measures in a clinical population under investigation which may predict functional outcome.

6. Follow clinical populations longitudinally and seek to distinguish plasticity of the CNS vs. Compensation in recovery of gait function, critical periods of opportunity for plasticity of the CNS post injury and treatment intervention choices.

7. Address a variety of locomotor functions in clinical populations, not just overground locomotion but transitions to locomotion, obstacle avoidance, speed changes in locomotion, unlevel surface locomotion and locomotion patters other than 2 feet (e.g., power w/c, manual w/c-one hand, one foot; two hands; one hand).

8. Utilize appropriate control groups from which to compare treatment efficacy. For example, investigations into the efficacy of a particular physical therapy treatment on the gait of individuals post-stroke usually reveals that the control group is receiving conventional PT. In other words, treatment with a theoretical framework based on the writings of Brunnstrum or the Bobaths. Presently the motor learning framework is being advanced. These are not appropriate control

groups. The control group should be another group with equal time spent in conventional ambulation training.

9. Look at the best ways to educate health professionals and consumers regarding the merits of gait analysis for different clinical populations.

John A. Buford, P.T., Ph.D.

There are three basic issues in clinical gait analysis. First is the depth and quality of the analyses, second is the selection and optimal presentation of results pertinent to the management of the case at hand, and third is the definition of indications for the analyses and incorporation of the results into the clinical decision-making process. These three are linked. For example, if the goal is to decide between two possible canes, observational gait analysis combined with a stopwatch and a metered walkway may be adequate. Thus, the quality of the data need not be extravagant, the clinical decision making process would be straightforward, and the cost of an error would probably be small. On the other hand, if the objective is to decide whether a hydraulic or a friction knee in a A/K prosthesis results in lower shear forces in the skin of the residual limb, then a more sophisticated analysis may be indicated and the cost of an error could potentially be large.

Our central task is to identify branch points in the clinical decision-making process where alternatives may significantly affect functional outcome depending on how well the treatment of the identified gait deficit matches the appropriate response for the actual gait deficit. In other words, if the clinical observation led to an improper identification of the deficit, but some form of gait analysis (however simple or sophisticated) would have led to proper identification of the deficit, and the cost of applying the 'wrong solution' was significant in terms of the functional ability of the patient, then there is a problem that gait analysis can solve. Finding these critical branch points in the path of the clinician and showing how we can be helpful should be our first mission. In support of that mission, we need effective communication of results from reliable analyses.

Major Recommendations

1) Identify branch-points in the clinical decision making process where gait analysis would change the decision, the resulting treatment, and the functional outcome of the patient. Determine diagnosis (disability) specific indications for gait analysis and weight costs against benefits. Establish high-priority for research along these lines.

2) Achieve consensus for the reporting format of results of gait analysis through debate of issues and establishment of a process for selecting and maintaining standards. Limit participants to the clinical gait analysis community so that we, the most important consumers of the information, get what we want.

3) Achieve consensus for the standard accuracy requirements for gait analysis through debate of issues and establishment of a process for selecting and maintaining standards. Include participants from industry, end-users (gait laboratories), professional societies, and other stake holders.

Minor Recommendations

1) Kinetic analyses should be three-dimensional and should always include the influences of inter-segmental dynamics. Currently available software makes this straightforward. The old justification of expensive computer time and limited data storage space no long applies. The full analysis can provide critical details in rapid parts of the cycle (e.g., pre-swing, swing or running).

2) The scope of "gait labs" must be expanded to include "motion analysis" in a more generic sense. Research along the lines of Major Recommendation 1 should be a priority to see if and how we can help, for example, in the management of upper extremity movement disorders and other problems aside from gait.

Carmen L.N. de Castro and Licia Saadi, M.D., Msc

Our suggestions for future work and development:

1 - Hardware and software advancements

a) Visualization systems - linking objective data with subjective observations through the use of representations data upon video recording.

b) Real time operation - to reduce the data time elaboration, to improve the accuracy and permit the use in clinical situations that requires fast comparison of information like orthosis and prosthesis alignments.

c) Creation of dedicated software to evaluate the equipment precision - to evaluate the calibration's effectively during all homogenous acquisitions.

d) Development of analysis of another relevant locomotor tasks - like stair ascent or descents, rising from a chair.

e) Creation of dedicated software to assess locomotor function for specific applications - joining stride, kinematics, kinetics, and muscular function measurements with evaluation of postural steadiness and energy consumption that can indicate the disability in several clinical conditions: stroke, fall prevention in geriatrics, Parkinson's disease, amputees, cerebral palsy, etc.

2 - Co-operation between gait centers

a) To share experience and expertise and greater dialogue between the centers and clinical community - in order to develop clear reasonable objectives would be particularly beneficial.

b) Determination of guidelines in methodology of the several equipments for movements analysis to clinical use - including data normalization, units standardization, form and method of data presentation.

3 - Medical Education - education of medical specialists about:

a) Indication of instrumentation requirements as better diagnostic tool in specific pathological groups - for example: the quantification of pressure distribution under the diabetic foot requires a baropodometer while the orthoses and prostheses proper alignment evaluation requires the measurement of force vectors by a force plate. A correct interpretation of electromyogram of a cerebral palsy child requires a foot switch or camera recording of joint kinematics.

b) Indication of the best locomotor task to analyze specific pathologies - It seems that many knee pathologies are better analyzed during stair ascent or descents and rising from a chair can stress the hip more than gait.

D.S. Childress, Ph.D.

1. Language, nomenclature, and definitions continue to produce communication barriers that impede progress toward clinical application of "gait analysis." International standards development, similar to what happened with EKG analysis 50 or more years ago, will need to come about.

2. Gait analysis equipment needs to be located in clinical environments where it is easily accessible by clinicians who are looking for solutions to real problems.

3. Gait analysis laboratories need to be problem driven, not technology driven. Problem setting needs to be clinically based. Gait analysis results need to answer questions related to real problems that cannot be answered in any other way.

4. The issue of data overload must be addressed either by simplification methods (data reduction) or by development of better graphical display systems, etc.

5. A significant proportion (say 20%) of the activities of clinical gait laboratories needs to be directed toward hypothesis testing, not merely data gathering and analysis.

6. Visualization systems need to be developed that bring together subjective and objective domains to assist with communication between clinicians, engineers, and scientists and to assist in the process of understanding.

7. Some "real-time response" modalities need to be available for experimentation that is response directed.

8. Modeling and theory are not developed to the point that allow models and theoretical principles to be used to aid analysis, interpretation, instrument improvement, etc.

9. Simple, easy-to-use, low cost, low maintenance systems--perhaps dedicated to specific pathologies--have yet to be developed and should be considered.

10. It may be incorrect to base clinical treatment decisions on a kind of differential diagnosis that relies mainly on comparisons of pathological gait data with so-called normal gait data.

Kim Coleman, M.S.

The field of gait analysis is challenged to prove its worth. Because the work is still largely descriptive, research laboratories often encounter great difficulty securing funding in a climate which demands results clearly applicable to clinical and commercial endeavors. Clinical laboratories work to move beyond description by applying technical analyses to medical and rehabilitation interventions. But because there are a few widely accepted standards for translating description into prescription, the approach to clinical gait analysis varies considerably across sites.

In order to significantly advance the application of gait analysis to rehabilitation medicine, I believe we must 1) strengthen the link between scientific investigations of gait and the clinical application of results, and 2) assimilate the data and insights gained through the many site-specific approaches to clinical gait analysis and begin to build a more unified standardized approach. To accomplish this, the two main areas on which I think we ought to focus are the development of standards and the dissemination of information.

Standards

A) Standards for the Reporting of Data from Academic and Clinical Research.

Because of the complexity of human gait, the subtle and interrelated nature of its deviations and adaptations, and the widely varying methods of study and reporting, the field of gait analysis has been slow to establish a comprehensive description of what we do know. The results of similar studies often do not agree, but even when they do, it can be very difficult to determine how they fit with those related studies to broaden the overall understanding of gait.

We are faced with the challenge of assimilating the vast amount of gait data available into a comprehensive picture. Already organizations like the International Society of Biomechanics, the CAMARC group, the Scoliosis Society, and the Clinical Gait Analysis Group have begun to take steps in that direction by working to establish standards for the reporting of data. The ISB's Recommendations for Standardization in the Reporting of Kinematic Data, which was published in the Journal of Biomechanics last year and touched off a spirited debate in the field, is one such effort. I believe we need to extend these efforts throughout the field.

B) Standards for the Assessment of Function: the Link between gait analysis and clinical intervention.

The clinical identification of gait abnormalities through detailed laboratory testing and analysis has become quite common. However, we are much less adept at assessing the consequence of a given gait deviation to a patient's functionality in his/her life beyond the walls of the laboratory. The gait pattern employed by a person at any one time results from a complex interaction of many factors such as skeletal structure, muscular strength, joint range of motion, physical pain, level of fatigue, and emotional state. Consequently, it is often tricky business to determine whether an observed gait abnormality is a beneficial or detrimental adaptation. To complement the descriptive capabilities of laboratory gait analysis, we need tools which reach outside of the laboratory and into the patient's normal daily environment to give feedback on what the patient is actually able and choosing to do. In other words, we need a general, widely accessible means of measuring real world functionality which will provide the framework from within which specific measures of gait character can be interpreted for the purposes of prescribing and guiding treatment , and assessing outcome. The measures should be simple and inexpensive to obtain, and straight-forward to interpret. They should reflect, rather than be confounded by, day-to-day variability in actual gait functionality. Finally, they should be understood to represent a gross overview somewhat like age, height, weight and blood pressure do in general medicine.

To effect this link between gait laboratory testing and the clinical application of results, I believe we ought to take the following steps:

1. Establish standard definitions of real world ambulatory functionality. These might be similar to the Medicare functional level classifications set forth in the 1994 DMERC Policy for Lower Limb Prosthetics, but based on more measurable parameters.

2. Seek/develop practical, widely accessible "overview" measures of real world gait functionality based on the established definitions. Some factors I would like to see considered in the definition and measurement of real world functional levels include:
   - the ability to perform high intensity bursts of activity
   - the ability to sustain given levels of activity
   - the ability to maintain mobility after periods of activity
   - the ability to negotiate obstacles and varied terrain
   - the spontaneous/deliberate quality of activity
   - the overall amount of activity performed.

3. Validate the overview measures with respect to their ability to provide:
   a. meaningful, standardized assessments of functional status.
   b. reference for guiding the interpretation of more detailed gait laboratory testing.
   c. standardized means of assessing outcome.

<u>Dissemination of Information</u>

In conjunction with establishing standards for the reporting of gait data and the assessment of functionality, I believe we ought to establish a digital forum for the communication and assimilation of results from academic and clinical research world wide. The expansion of Internet/Web technologies has recently enabled rapid and widespread international communication among researchers and clinicians in all fields. Already, groups such as the ISB have established data bases for research results which can be accessed by members over the Web. I believe we are in need of a clinically-oriented data base through which gait analysis data can be reported, evaluated, assimilated with other clinically-relevant data, and accessed efficiently.

Rory Cooper, Ph.D.

Gait analysis has been used to describe locomotion of people for years. A vast majority of the gait analysis research has focused on the lower extremities. Some work addresses locomotion of unimpaired individuals, other work on athletes, and still other work on people with various physical impairments. The trend for the future is towards greater study to understand, prevent, and treat injuries. Although, work in sports is likely to continue. Human gait analysis is traditionally defined as the study of bi-pedal locomotion with the lower extremities. Within this definition, gait studies have included ambulation with prostheses, ambulation with orthoses, and ambulation without assistive devices. Gait research has been helpful in understanding walking and running for people with and without various forms of impairments. Several conferences have been held, and research priorities have been implemented. However, gait analysis needs to take a broader view within rehabilitation.

Ambulation which is performed with the use of the upper extremities has not received adequate attention. However, pushrim driven wheelchairs, arm propelled lever driven devices, arm crank driven devices, and electric powered wheelchairs are all important forms of ambulation, which require further research and development. Although these forms of mobility are not classically defined as "gait," they do exhibit distinct patterns which are identifiable, and alterable. Moreover, conservative and aggressive therapies have been developed to treat people with disabilities who use their upper extremities for propulsion without substantial biomedical analysis. Studies have shown that a majority of long-term manual wheelchair users develop repetitive strain injuries. The progression of RSI presents several complex clinical research questions. Often, wheelchair users do not have the range of mobility options which are available to people who can walk. Wheelchairs are also evolving, and quantitative studies are required to determine their safety, efficacy, and proper fit. Gait research for upper extremity, wheeled locomotion can help to address RSI, propulsion efficiency, postural support during propulsion, and activities of daily living. This research will lead to better wheelchairs, and provide guidance for clinical practice.

Pushrim propelled wheelchairs are slowly being augmented by other means of manual wheeled mobility. Arm-crank and arm-lever drive wheelchairs are becoming more popular as mobility devices, recreational devices, and as exercise devices. Biomedical analyses of these devices is required to insure their safe and effective design. The devices offer substantial promise for improving the health and well-being of many people with disabilities.

Research into this area could help reduce the incidence of RSI, and cardiovascular disease.

Electric powered wheelchairs may not be thought of as gait, but the methods developed through gait analysis can be applied to improve the mobility of people with arm impairments. Issues of dynamic stability and postural control during electric powered wheelchair driving are gait questions. Positioning of input devices for optimal control of the wheelchair in a variety of environments is also an important research problem. Another very pressing question for researchers and clinicians is when to choose an electric wheelchair over a manual wheelchair. There are many clinical, social, and personal, implications associated with this decision. Further research is required to provide a foundation for selecting the appropriate answer for each individual.

Lower extremity gait analysis has made many important contributions. The definition of gait among lower extremity researchers has been broadly defined. Within the context of rehabilitation, alternative forms of mobility are of paramount importance. Gait analysis must include analysis of motion controlled by the upper extremities. The combined resources of the lower extremity gait researchers, upper extremity gait researchers, and rehabilitation professionals can have tremendous positive impact on people with disabilities.

Rebecca Craik, Ph.D., P.T.

The gait literature is filed with rich *descriptions* of walking performance detailing how walking differs with age, sex, body weight, etc. An assumption underlying the descriptions is that understanding "normal" performance will provide a foundation for understanding the walking strategies adopted in the presence of pathology. A single variable has not been identified that, like body temperature, serves to screen for the presence of pathology. Instead it is usual to find statements in the literature concluding that a complete evaluation of gait requires the collection of kinematic, kinetic and electromyographic variables.

The approaches to research, clinical evaluation and treatment of problems of gait have not differed significantly from the times of Eberhart, Inman, and Saunders. We have fancier tools to measure more and very complex variables, but we still don't know what to measure, how to use the measurements to guide treatments, or how to treat across a variety of medical diagnosis. The relationship between the nervous system, the musculoskeletal system, the environment and function remains unknown. We have a long way to go.

Some suggested needs:

1) Determine what the reference standard is in gait for persons with an array of functional problems. Is the goal of treatment to restore function or to help the person compensate? The goal should influence the standard by which performance is evaluated.

2) Move beyond description of walking ability and identify modifiable factors, i.e., those that are amenable to treatment.

3) Develop a model of walking performance that identifies major determinants of gait. Intervention will continue based on the untested assumption that there is a relationship between some impairment and disability until major determinants of recovery are identified.

4) Develop a model of walking performance that merges neuroscience, biomechanics, and function.

5) Develop a classification scheme of walking performance that moves the clinical away from medical diagnosis and towards a focus on functional ability. The classification scheme would lead to critical paths for selective intervention.

6) Determine functional requirements for walking that relate impairment, disability and handicap.

7) Shift attention beyond biomedical factors that limit recovery of walking ability to include psychosocial factors.

8) Determine the effectiveness of intervention on reducing the discrepancy between optimal and actual recovery of walking ability.

Diane L. Damiano, Ph.D., P.T.

Rehabilitation medicine serves to improve the lives of individuals with disabilities, and assessment tools such as clinical gait analysis must contribute to this mission if they are to be successful. While few would argue the value of gait and motion laboratories for the advancement of biomechanical knowledge of normal and pathological movement, the extent of their clinical applicability is still controversial. Unlike radiographic technologies such as X-ray, computed tomography, and magnetic resonance imaging, gait analysis has failed to establish itself as a necessary clinical service. In addition, clinical utilization of gait laboratories is limited not only by philosophical differences in medical practice, but also by geographic or financial inaccessibility.

So why is it that gait analysis has failed to attain the mainstream support of the medical community? Gait analysis has been used extensively to evaluate the complex multi-joint gait abnormalities in cerebral palsy, but even for this population no documentation exists establishing that the use of this assessment leads to improved functional motor outcomes. Gait analysis can objectively document motor status in an ambulatory individual at a single point in time or measure very precisely the change in ambulatory function over time. However, its ultimate importance rests on whether its use alters treatment decisions in a positive direction. Therefore the central issue is this: *Does the addition of gait analysis in the clinical assessment of a person with a disability contribute substantially to improving treatment outcomes, or could the same result be achieved in the absence of gait analysis?* If gait analysis does indeed improve outcomes, then gait laboratories should become a standard of care for those with complex walking disorders. This should then spark an increase in the number of laboratories and their usage, and accessibility should (within a reasonable amount of time) no longer be an issue. However, if gait analysis is shown to be a useful evaluative tool but yet does not appreciably affect outcomes, survival as a clinical service would be seriously impaired. We in this field need to be proactive by conducting or facilitating research that demonstrates the clinical effectiveness of gait analysis in minimizing disability.

A second major issue concerns the validity of the two assumptions that are implicit in the use of gait analysis in rehabilitation medicine. The first assumption we make is that walking is an important skill to these patients and their families. Indeed, one of the first questions that parents will ask when informed that their child has cerebral palsy is, "Will my child ever walk?" Most of the interventions offered throughout childhood, and even extending into adolescence and adulthood, such as bracing, surgery and physical therapy, are aimed at improving or maintaining this skill. However, the patients themselves must determine the importance of walking in their daily lives, since all of these interventions have physical, emotional, and financial trade-offs associated with them. The second assumption is that gait ability is representative of performance on other motor tasks. Gait laboratories have responded to this concern by expanding their assessments to include different aspects of gait such as stair climbing and fast walking, or by adding assessments of energy cost and other functional and disability assessments concurrently. As the clinical scope of gait analysis broadens to more comprehensively assess gross motor performance, the ability of these laboratories to assess functional outcomes should similarly increase.

In conclusion, as gait analysis laboratories have proliferated, so has the scientific body of knowledge on cerebral palsy as well as other neuromotor and musculoskeletal disorders, enhancing our understanding of the motor pathology and altering the types of interventions prescribed. I am confident that gait analysis will continue to be a valuable assessment and research tool in rehabilitation medicine, and I hope that future research will provide justification for the incorporation of gait analysis as a standard practice for clinical decision making in persons with disabilities.

Howard J. Dananberg, DAM

Gait analysis is a broad topic reflecting many technologies combined to view a wide range human locomotive dysfunctions. In the cost conscience medical marketplace however, the application of *all* of these technologies for *each* case may not be an effective utilization of services. This position paper describes the use of in-shoe plantar foot pressure analysis during gait combined with two view-video analysis as a cost effective method of treatment for patients with chronic postural pain (CPP) (i.e., lower back pain). While the all encompassing measurements required for scientific research are a necessity, a relatively simple gait assessment is highly acceptable for its clinical application in the CPP patient population. An explanation as to its rational, methods and effectiveness follows.

In normal, bipedal human walking, it is essential to step up and over the weight bearing limb. For this to occur, the thigh extends out from under the hip, as the body simultaneously advances forward over the planted foot. The foot, through a highly complex mechanism, serves as a functional pivot or fulcrum point while bearing the full weight. Sagittal plane (forward) motion of the body over the foot is thereby permitted and coupled with concurrent self bracing mechanisms of not only the foot, but the lower back, head and neck as well.[1,2] Although taken for granted, this complex sagittal plane pivot fails far more commonly than previously recognized and can upset the chain of events in the entire body as it attempts to pass over it.[3] Due to its subtle nature, it has been overlooked as a potential cause to other CPP entities yet can be detected using plantar foot pressure sensing technology. Many seemingly unrelated CPP syndromes resolve when a failure of this sagittal plane motion of the foot joints is objectively assessed and treated. In a paper published in 1990[4] and subsequently referred to in other publications,[5,6] 77% of patients having failed multiple prior therapies and considered at medical endpoint for chronic postural pain (i.e., lower back pain) demonstrated 50-100% improvement at a two year F/U point when primary sagittal plane motion blockage at the foot was addressed. This is despite the fact that no obvious foot symptoms were evident in any of this patient group. The results of pain reduction are understandable through well established research previously performed within the neuroscience community on the function of pain sensing nerves (primary afferent nociceptors). Their transmissions appear to be modulated (transmission threshold of pain increases or decreases) based on their interrelationship with motion detecting proprioceptors (A and A mechanoreceptors). Constantly repeated abnormal motion patterns (typical of walking) act as a repetitive strain type injury and sensitize the common nociceptive/proprioceptive synaptic sites (wide dynamic range cells) in the spinal cord. Chronic pain is perceived and perpetuated by continued aberrations in subject's gait. Once detected, this cycle can be broken by a treatment method which can produce normal motion patterns and can specifically relate to sagittal plane foot function. The lasting effect described in the study cited was achieved when patients were evaluated via gait analysis using two-view video examination to verify the effects of custom foot orthotics objectively fabricated using in-shoe plantar foot pressure sensing systems. Due to the physics of weight transfer, the appearance of the force/time curves calculated by in-shoe plantar foot pressure sensing systems can be used to determine the effectiveness (or lack thereof) of sagittal plane motion during single support. The classic, normal double hump curve can depict sequential sagittal plane pivot when viewed segmentally (heel/forefoot). Detection of sagittal plane motion blockage by viewing variations in curve shape is possible (flattening of the central depression, shifting of the higher peak to the heel from the forefoot, examining total heel contact duration and comparing left to right, alterations of the slopes of the curve within the central depression, etc.) due to failures in various foot motions to occur at specific times. A test foot orthotic capable of altering sagittal plane motion can therefore be fabricated, then evaluated and adjusted repeatedly until the desired effect is achieved. This effect is confirmed by easily identifiable motion markers using a two-view video system to assess pre-test and post-test orthotic fabrication. These markers include hip extension during single support, arm swing symmetry, direction of hip and knee joint motion during single vs. double support phase, torso motion, shoulder drops, head tilts and movements. Due to the relatively inexpensive nature of inshoe pressure and video systems, this type of examination can be used in the rehabilitation of lower back and other CPP patients in any community based medical setting and can therefore have long-term cost saving benefits.

Recommendations:

1) Establish a research program which can correlate foot level sagittal plane motion with plantar foot pressuring sensing analysis.

2) Develop interdisciplinary working groups to facilitate communication channels for the propagation of clinically relevant information.

3) Both government and private industry fund interdisciplinary research which can explore cost effectiveness via outcome based study of inshoe plantar foot pressure sensing analysis combined with two view video analysis for the evaluation and treatment of lower back and other chronic postural pain patients.

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Roy Benjamin Davis, III, Ph.D.

Over the past 15 years, clinical gait analysis has found good utilization in the assessment of pathological gait where motions are often complex and difficult for the fixed observer to fully appreciate. The most wide-spread use of clinical gait analysis is for the evaluation of persons with cerebral palsy in treatment planning (predominately orthopaedic surgery associated with tendon transfer/release, muscle lengthening, derotational osteotomy).[1-4] Other examples of clinical pathologies currently served to some degree by gait analysis include amputation, degenerative joint disease, poliomyelitis, myelomeningocele, stroke, and traumatic brain injury. Clinical gait analysis is also useful in the documentation of gait-related changes that occur because of treatment (again predominately associated with surgery). This clinical research is vitally important in the enhancement of the knowledge base associated with analysis, both on a patient-by-patient basis and also in studies that examine the functionality of a particular brace design.[5]

With this basis, how can clinical gait analysis approaches be strengthened further and its use be expanded with respect to Rehabilitation Medicine?

1. While gait data collection processes have matured over the past decade thereby producing more accurate and reliable information for interpretation, challenges remain. Most notably, gait models based on more reliable joint centering algorithms (particularly for the hip) would improve further gait analysis results associated with joint kinetic information. Even more importantly, gait models that either account for or are less susceptible to "skin movement artifact" would substantially improve the quality of the data (particularly those data associated with patients with obesity).

2. Additional clinical research is needed that documents changes in gait biomechanics associated with different patient treatment approaches. This research in particularly important in treatment alternatives commonly employed in Rehabilitation Medicine, e.g., physical therapy, orthotic management. As indicated above, this outcome research is essential for improving our use of clinical gait analysis data.

3. Formal training in gait analysis techniques and its clinical application must be expanded. In general, exposure by physicians and other clinicians to clinical gait analysis during medical school and residencies is limited. This impedes the incorporation of gait information in the treatment decision-making process. At the same time, gait analysis technologies must continue to strive to improve the ways in which gait information is presented for clinical interpretation.

4. The expense of gait analysis may be an impediment to its increased clinical utilization in Rehabilitation Medicine. A typical charge for a full clinical gait analysis ranges from approximately $1,000 to $2,500 depending on the facility and the specifics of the service

provided. This amount is consistent with the amount of time that is allocated to gait data collection, processing, interpretation, and report generation. Relative to the cost of surgical intervention and in the context of its permanency, the expense of gait analysis appears generally acceptable to both consumers and payors. However, the current cost of gait analysis may impede its use in clinical decision making associated with generally less expensive treatment alternatives such as physical therapy, the administration of spasmolytic medications (e.g., Baclofen), and orthotic use. Consequently, efforts to improve the efficiency of clinical gait analysis processes may be warranted, i.e., improving its either perceived or actual cost/benefit ratio.

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Robert C. Dean, Jr.

Gait Analysis is an important tool for fitting/aligning lower-limb prostheses. V02 measurements demonstrate that walking power varies considerably as a function of the quality of the socket fit, for both trans-femoral (AK) and trans-tibial (BK) amputees, and with the alignment of the mechanism. It is especially important to AK's that the geometrical parameters be correctly set; that is, the angles and offsets between: socket axis, knee-rotation axis, shank axis, ankle axes and foot centerline. Customarily, alignment is based upon visual observation by the prosthetist of the amputee walking over a short path (usually 3-5 m), forcing the amputee to turn frequently. Research shows that at least three strides are necessary to reach steady-state so the simulation of ordinary ambulation is usually poor. Most often, there is no simulation of walking on rough ground, and of the most hazardous for AKs... the excursion of downramps. Rarely is the speed of walking varied. For the BK, running performance is ignored.

Research at SII has demonstrated that the use of a special treadmill which can be pitched up or down angled left or right with speed variable from 0-10 mph is a very useful, and a relatively inexpensive tool for prosthesis alignment. The addition of a force plate under the belt and a belt-tension dynamometer, with V02 instrumentation and intersocket pressure measurements can yield a complete set of vital information about gait, power demand and, eventually we hope, a direct measure of the quality of socket fit and prosthesis alignment. We call this gait analyzer an "Ambulation Simulator."

The most important characteristic of a lower-limb prosthesis is the interface between the amputee's anatomy and the mechanism i.e., the socket interface. The majority of amputees report unsatisfactory, even painfuted with his/her prosthetist and moves, as frequently as possible, to another prosthetist. This is very expensive therapy given that AK prostheses today in the U.S. costs AKs $10-20,000 and BK, $6-12,000. One of the principle reasons for the high cost is that the prosthetist finds it necessary to produce 2-5 trial sockets before a "satisfactory" fit is achieved. But, that fit is "satisfactory" to only 25% of lower-limb amputees.

CAD-CAM has been applied extensively for manufacturing sockets, but with no better results than the conventional art produces. That is, CAD-CAM cannot generate the critical fit between anatomy and socket. Today, it is only the hands of an experienced prosthetist that can achieve a "good" fit and that fit is not really "good" with or without CAD-CAM, and even with the hands of a most accomplished prosthetist.

Our research has now identified the reason for this wholly unsatisfactory situation. That is, the stump anatomy is constantly changing in volume, for both BK and AK amputees. For example, active BKs sometimes require the donning of one stump sock in the am, with the addition of four more socks during the day! Personal experience (54 years as an AK) proves that my stump changes volume diurnally by 60 mL/1500 mL (4%). Tests with SII's variable-geometry socket reveal that the AK amputee can sense a volume change of < 1% as "looseness," insecurity (especially for full suction retention) and, with a variation of 1%, the output of unsocial noises. There is no way that even the world's best prosthetist can fit a stump which varies diurnally 4% in volume. The problem is more severe for women with a large monthly volume change (5-10%) added on top of the diurnal variation. Similarly, for kidney dialysis, illness and exercise.

There is no science of socket fitting today because there is no commercial equipment available to accommodate the volume fluctuations of the residual limb. However, variable-geometry sockets should become ubiquitous for the lower-limb amputee within the next decade. Likewise, by use of the Ambulation Simulator described above, a data bank of dynamic pressure distributions during ambulation could become available to guide the prosthetist in designing the socket and testing the quality of fit.

Given the current need and the projection above, the Ambulation Simulator should become a widely-used tool for lower-limb prosthetists, and within the next decade. The cost to the Nation of providing the Ambulation in prosthetic rehabilitation which will obtain.

Sandra W. Dennis, P.T., MSHCM

The application of computerized gait analysis to the field of Rehabilitation Medicine has undergone dramatic growth and many changes over the past two decades. The use of gait analysis to assist with surgical decision making has improved surgical outcomes and decreased health care costs. The growth and expansion of gait analysis laboratories throughout the United States has created several issues which need to be addressed if gait analysis is to remain a viable tool to assist with treatment planning. Several of the issues that need to be addressed to advance the field of gait analysis are listed below:

1. Steps need to be taken to ensure adequate funding for clinical and research activities performed in gait analysis laboratories. If adequate funding is not available gait analysis laboratories will not be able to continue providing services. Steps must be taken to standardize the services provided by gait laboratories (see number 3), to educate third party payors and funding agencies as to the value of gait analysis, and to work to establish accepted reimbursement codes for the services provided.

2. Additional research is needed to document the value of gait analysis in Rehab Medicine. Improved collaboration among gait laboratories to participate in multi -center research projects would produce more meaningful results. Standardization between gait laboratories and making public domain research tools more accessible would facilitate multi center research. Additional research is needed on the value of gait analysis from a quality of care and from a cost containment perspective. The results of previous and future studies should be utilized to educate physicians, third party payors and potential patients about the value of gait analysis.

3. Comprehensive gait analysis needs to become more standardized and a mechanism for accrediting laboratories needs to be established. This will allow physicians, health care professionals, third party payors, funding agencies and patients to be educated and will provide a consistent meaning when the term "gait analysis study" is used. This will also help to insure the quality and value of the services provided.

4. The ease and accuracy of data collection needs to be improved. A more accurate way of measuring the rotational deformities of the shank needs to be developed including a more accurate way of determining the ankle joint center. The data collection process remains rather complex and it would be beneficial to continue to seek ways to simplify it. Developing a way to collect motion data with a less cumbersome marker set would improve accuracy and decrease the complexity of the data collection process.

5. A way to look at the projected effect of a proposed surgery on the individual's walking ability needs to continue to be developed. This will provide an additional tool to assist with maximizing surgical outcomes.

These recommendations for advancing the field of gait analysis are overlapping and cannot be addressed in isolation. Accomplishing any one of these recommendations will have a positive impact on several of the other areas identified. Collaboration among health care professionals working in the various gait laboratories across the country is the key to successful advancement of the field. The areas to focus on must be prioritized and we must work together to achieve success and insure the future of gait analysis into the 21st century.

John F. Ditunno, Jr., M.D.

The analysis of gait dysfunctions has always been an integral part of Rehabilitation Medicine. Recently, the development and refinement of motion analysis systems which provide the ability to evaluate electromyographic, kinematic and kinetic aspects of gait has provided clinicians and researchers with objective data regarding gait dysfunctions. However, although the availability of such systems is increasing, the practical application of their use remains limited. In order to increase the effectiveness of this technology in providing patient care and as an outcome tool for research, the following recommendations are made:

- Develop easily utilized tools for the analysis and interpretation of the data collected.

- Develop more cost and space-efficient analysis systems.

- Develop guidelines on how to statistically manage the data for research purposes.

Daniel J. Driscoll, M.D., Ph.D.

One area that probably receives insufficient attention in gait analyses is the underlying biological basis for various gait abnormalities. Ameliorating the abnormality is certainly important, but equally important is understanding what caused it.

Identifying gene mutations that cause ataxia can lead to better understanding of the biological basis for the disturbance of gait. This knowledge can then be used to design rational therapies. For certain conditions the responsible mutant gene has been identified (e.g., Ataxia Telangiectasia and Friedreich Ataxia) or the chromosomal region localized (e.g., Angelman syndrome), while for other conditions (e.g., Cerebral Palsy) there are still many mysteries as to the etiology.

Recommendations: Encouraging research to identify the biological bases for various gait disturbances including the role certain genes play.

Jack R. Engsberg, Ph.D.

In order to effectively assess the efficacy of a given treatment it is necessary to have outcome measures that encompass many domains related to medical rehabilitation. The National Center for Medical Rehabilitation Research (NCMRR) of the National Institute of Child Health and Human Development (NICHD) at the National Institutes of Health (NIH) has defined five domains: 1) Pathophysiology (interruption of or interference with normal physiological and developmental processes or structures), 2) Impairment (loss or abnormality of cognitive, emotional, physiological, or anatomical structure or function, including all losses or abnormalities, not just those attributable to the initial pathophysiology), 3) Functional Limitation (restriction or lack of ability to perform an action in the manner or within the range consistent with the purpose of an organ or organ system), 4) Disability (inability or limitation in performing tasks, activities, and roles to levels expected within physical and social contexts), and 5) Societal Limitations (restriction, attributal to social policy or barriers, which limits fulfillment of roles or denies access to services and opportunities that are associated with full participation in society).

Results from gait analysis would be one example of an efficacy measure in the Functional Limitation domain. While gait is a very important functional measure, at least two limitations must be recognized with its use. The first is that it only evaluates gait and the results may not be extrapolated to other important functional activities. For example, results from a gait analysis do not measure the ability to transition from sit to stand or bed to chair. Measures taken from these or other functional tasks may be even more relevant than gait since they affect more of the disabled population than gait. The second limitation is that the results for a gait analysis may not be appropriate for outcome assessment in other domains. For example, during an evaluation, gait analysis may identify that an impairment is present at the ankle. However it cannot assess the level of impairment since during gait the ankle is generally not move through its greatest range of motion. In a normal ankle during gait the total excursion is about 30 degrees, yet over 65 degrees of excursion is generally possible. Separate impairment measures quantifying total ankle range of motion, maximum joint torques, or power adjunct to a gait analysis may be more appropriate.

Gait analysis is one important tool in evaluating efficacy in the functional domain. However, it should not be considered the only functional activity that should be evaluated, nor should its results be used in assessing outcomes in other domains. Additional tests in the functional domain relevant to the population of interest and other efficacy measures specific to their respective domains should be integrated to produce a comprehensive outcome assessment.

Alberto Esquenazi, M.D.

Introduction and Overview

Conventional gait analysis may be thought of as the observation, measurements, quantification and analysis of physiological and mechanical walking parameters in order to make a clinical decision on how to improve gait. As such, modern gait analysis laboratories have the potential to evaluate the causes, outline suitable short- and long-term strategies for treatment, and to gauge progress and measure efficacy of interventions for gait and movement-related impairments.

Patients who are referred for gait evaluation often include those patients with neurological or orthopedic condition that affect the motor control system (e.g., brain injury, spinal cord injury, cerebral palsy, stroke, multiple sclerosis), musculoskeletal actuator systems (e.g., post polio, peripheral nerve injuries as well as orthopedic trauma/injuries or joint degeneration and amputation). This types of dysfunctions may necessitate one or more of the following modes of intervention: physical rehabilitation, pharmacology, mechanical interventions and surgery. Physical rehabilitation may include exercises to increase range of motion, strength and/or coordination nerve and motor point blocks using phenol and botulinum toxin are common modes of pharmacological intervention to relieve spasticity or to improve contractures when combined with other interventions. Common mechanical intervention include using wedges and lifts in shoes, splinting, bracing, orthotic and prosthetic alignment modifications, as well as recommendations for surgery.

In order to make recommendations as noted above, physical data is often collected. The most common type of such data is visual. Visual inspection of gait combined with a physical examination reveals a great deal about the walking dysfunction, but generally may be just the beginning pint for a more comprehensive instrumented gait evaluation. Electromyographic activity, temporo-spatial footfall parameters, whole body kinematics and kinetics, as well as energy consumption (metabolic or mechanical) data may need to be assessed. Modern gait laboratories are capable of collecting all of the above data and sometimes more in an attempt to understand what factors may be causing a particular dysfunction. Gait analysis technology allows data collection to be done in a relatively short period of time and with clinically useful accuracy. Equinovarus posture at the ankle foot system may be used as an example. At least five different muscle groups alone or in combination may be contributing to such abnormal posture (tibialis anterior, tibialis posterior, extensor hallucis longus, gastrocnemius and lack of peroneal activation). Dynamic EMG analysis permits specific muscle identification and enhances the ability to differentiate between the muscles contributing to ankle deformity allowing proper correction.

Gait analysis has come a long way towards achieving the above stated goal of obtaining a more complete understanding of the factors which produce the dysfunction that give rise to observed gait deviations. However gait analysis has not reached a state which allows such a clear understanding in all cases or for different environmental conditions.

Future Direction of Gait Analysis

It is not that current analysis methods have been providing spurious measurements. They are certainly useful and help to drive the clinical decision-making process in a large number of cases. However, current methods are only a part of the complete picture. The current analysis methods may be too narrow or are looking at only one or a few levels of this complex task. Traditional gait analysis has evolved around measuring quantities which can be seen or felt or measured in a controlled environment laboratory. Probably most sciences begin around information which is easily obtained - usually visual examination. To this day, this is still a large and important part of medicine in general and gait analysis in particular. Evolution has occurred in making more things "visible." EMG electrodes allow us to see, quite literally, when muscles are working properly, out of sequence or when they are not working at all. Motion analysis systems have made information about the forces and moments across joints fairly readily available. Our scope of vision has expanded over the years. We have advanced from observing the motions of the body to understanding the forces which give rise to those motions. Hopefully this has taken us one step closer to the source of the problem and the potential solutions.

It is common practice in medicine to search for the causes of a problem and base the solution around that rather than to merely treat the symptoms. In like fashion to truly understand some of the more complex problems which confront clinicians in gait analysis today, it is important to fully understand the source of these problems. An example of such problems may be in the area of compensation mechanisms employed by patients with gait deficiencies. What gives rise to these compensation mechanisms? How is one scheme selected over other options that are potentially available? What are the criteria employed in choosing the selected response? (e.g., safety, speed, energy efficiency, etc.). The answer indeed lies in understanding how the brain processes information and perhaps even more importantly, *what* information the brain selects to make such a decision. The limitations of our current purely physical models is a good indicator that more information and likely information of a different type is needed to fully understand this problem.

Perhaps we can analyze gait under different environmental conditions, physical demands or perhaps measure different areas - at the motor control or neural level as opposed to the currently physically observable/tangible level or measuring forces, movements, muscle activities.

Gait/biomechanics scientists have models which are very complex from a purely mechanical standpoint - and they have not been sufficient to predict how movement patterns occur. This may be perhaps because the motor control/neural input levels haven't yet been included in the models. Even the "neural network" models which, despite the eponymous relation to a higher level of input, have been largely unsophisticated enough to completely and accurately characterize gait. This may be due to the fact that although they implicitly include physiological data from the neural level, these data are only by accident or by luck. As scientists, we have not been able to explicitly include such inputs. But due to the way in which neural networks pair inputs to outputs, generating maps/links/relationships between physiological input and output data may have taken preliminary steps to providing at least at some level a "neural" input. In any case, the explicit data used in most neural network models has been still of the physical nature - such as forces, joint moments, powers, spatial orientation, joint angles, muscle activity and the like, and thus they are in reality no more sophisticated in terms of their ability to fully characterize gait than are the traditional mathematical musculoskeletal models of the past.

It is unclear, today, how to incorporate neural input into existing models, or what other parameters or information we should attempt to record to better understand the very complex task of walking. Undeniably other steps need to be explored in our search to move the understanding of gait to the next level. With information that better describes and assess gait we will be able to develop and apply the best treatment interventions to the benefit of our patients.

Virginia Graziani, M.D.

The analysis of gait abnormalities has been an important part of Rehabilitation Medicine for many years. Recently, there has been an increase in the number of clinical gait laboratories as well as an increase in the literature of the use of these assessments in evaluation of gait disorders and interventions. Gait analysis can be useful in planning treatment for individual patients, most importantly in pre-operative evaluations, as well as in evaluating prosthetic and orthotic devices. These assessments may also be used to objectively evaluate pharmacological and surgical interventions that are intended to improve gait in certain patient populations. However, gait analysis has not yet gained wide spread use clinically. Some of the issues that may contribute to this are that clinicians feel that this technology may not be easily accessible to their patients, that the procedure may be too cumbersome or painful, and that the information obtained may not be clinically interpretable. As a research tool , there is reluctance to use this technology because of concerns regarding the analysis and interpretation of the large amount of data generated, as well as the time it takes to collect the data.

In order to promote the effective use of gait analysis for clinical and research purposes, working groups of gait specialists should reach a consensus on several issues, including:

A minimum data base necessary for analysis. Although all laboratories should be able to assess all types of disabilities (i.e., general laboratories as opposed to a specific laboratory for amputees, a specific laboratory for cerebral palsy), the minimum data base needed for a specific disability may vary.

-Recommendations regarding the interpretation of the observed abnormalities and the potential causes of each abnormality.

-Guidelines regarding recommendation to be made (and by whom) in reference to potential interventions to address the abnormalities demonstrated (i.e., surgery, injections, oral pharmacological agents, intrathecal baclofen, therapy program, orthotics, etc.).

-How to practically handle large number of patients or multiple assessments for research purposes.

-How to statistically analyze the data generated for research purposes.

Clear recommendations and guidelines provided by a group of gait specialists will further the effective use of gait analysis for individual patients as well as in outcome analysis of treatment interventions for specific patient populations.

Nasreen F. Haideri, M.E., B.S.

Gait Analysis as a Clinical Decision-Making Tool:

Is gait analysis a useful clinical decision-making tool? This question arises again and again, but still we have little documented proof that gait analysis leads to improved surgical decision-making or treatment intervention. Providing this documentation is a difficult assignment, in fact traditional methods of clinical decision making have never had to be validated as astringently. Several authors have demonstrated the accuracy of gait analysis over visual observation which has helped to validate clinical research. Others have utilized gait analysis to document outcomes associated with specific treatment regimes. However, few have defined specific functional measures to identify and describe particular impairments. More published work in this area would provide clinicians with information necessary to incorporate gait analysis techniques into their practice. There are several hindrances, discussed below, which will require attention in order to facilitate this type of applied gait analysis research and thus promote the expansion of gait and movement analysis in rehabilitation.

Standardization:

A major setback in the development of gait analysis as a clinical tool is the lack of standardization. Some steps towards this have been taken, for example, Winter's ad hoc committee which devised standards for reporting electromyographic data and, more recently, Ounpuu's compilation of terminology which was present to the AACP&DM Gait Lab Committee in 1994. Standardization would provide a framework and language to allow the results of gait analysis to be taught and transmitted universally.

Labs which conduct gait and movement analyses should be subject to accreditation or certification by some standards. Lack of this process has allowed several manufacturers of video capture equipment to advertise inexpensive gait analysis systems and many facilities which take sequential pictures of patients walking to call themselves gait labs. It is not necessary to immediately impose strong criteria to allow facilities to consider themselves certified, but rather distinction should be made between those facilities that actually generate evaluations with treatment recommendations and those that do no more than provide video documentation.

The first step in this has been accomplished, we have formed a society, the North American Society for Clinical Gait and Movement Analysis. This society should now advance the development of standardization and accreditation.

Modeling:

The development of diagnosis specific models will be required to allow application of movement analysis on a wider range of pathologies. Our institution sees patients with a variety of diagnoses characterized by atypical anatomy. Examples of this are patients with clubfoot, slipped capital femoral epiphysis, amputees, leg length discrepancy, and dislocated hips. Most of the clinical models commercially available for gait analysis have incorporated work done on normal adult anatomy to obtain anatomical references such as relative joint center locations, segment mass moments of inertia, and muscle origin and insertion locations. Such parameters are not currently available for pediatric populations or pathological conditions. Clearly, this introduces error in analyzing patients with such unusual anatomical profiles.

Some research work is being conducted in this area. Several groups have been working on more extensive models of the foot, and mathematical computations for six degree of freedom models of joints are available. In the future, using imaging technology to be able to study the underlying pathological anatomy and implementing this into models of gait analysis would be beneficial. For example, patients with extreme femoral focal deficiency or shortening of the femur do not have a normal hip joint. In some cases, the hip is fused and the anatomical knee joint is used to flex and extend the hip joint of a prosthesis. At our institution, these patients often will have CT scans and 3D reconstruction done of their pelvis, hip and knee. This information has been used to pinpoint the actual joint location which can then be used in a gait model. Published research in these areas would be most useful.

Future Directions in Basic Research and Methodology:

We have done much work to facilitate automated collection of kinematic data. Analysis of movement began with sequential photography, moved into video, then with computer advances became more automated, until finally moving up to the passive I.R. systems commercially available. Electric goniometers and active kinematic systems have improved as well. As the new era of High Density TV and computer animation explodes, there may be much to offer the field of gait analysis. Perhaps markerless kinematics will become feasible as resolution of video improves. Advances in imaging techniques combined with increased accuracy of motion data and computer animation could allow surgeons to better visualize and quantify precise deviations of a patient from normal. Once the effects of treatment intervention are more thoroughly quantified, it is possible that clinicians could actually try out different interventions on modes of their patients and visualize the probable outcome.

There is always the need for basic research prior to advancing applied research and clinical work. One area of basic research that is just beginning to surface in the clinical domain is control system theory. Forward solution models used to predict the behavior of biological systems will provide a more comprehensive understanding of the CNS, its control mechanisms, and movement strategies. This will ultimately help advance areas such as the design of prosthetic and orthotic devices. Linear optimal control and fuzzy control methodologies need to be investigated to develop a controller which can regulate the movement of the body similarly to the CNS. More complex artificial intelligence systems are under development which contribute technology to advance this area tremendously.

Collaborative Research:

The key factor in the transmittal of basic research to the clinical domain is the facilitation of communication between engineers, doctors, and rehabilitation professionals. This communication is optimized by daily contact which requires that patient care facilities employ technical staff. Continued support of collaborative research efforts enhances opportunities for transferring technology. Communication at scientific meetings is essential and should be promoted whenever possible.

Howard J. Hillstrom, Ph.D.

It is my contention that the objective role of the foot and ankle in the lower extremity biomechanics of posture and locomotion has all but been overlooked. Clearly the 26 bones, 33 joints, and over 100 tendons, ligaments, and muscles of this complex structure can no longer be regarded as a rigid body with a simple hinge across the transmalleolar axis. Not only is the function of the foot and ankle poorly understood in individuals with neuromusculoskeletal pathology but in asymptomatic healthy individuals as well. The use of realigning conservative treatment strategies such as custom molded neutral position foot orthoses has increased in the popularity but the foundational research is lagging the application. Gait analysis is considered to have an important role in exploring etiology details, differential diagnosis, prognosis, and demonstrating treatment effectiveness in patients with foot and ankle pathologies. It is possible that pathologies up the kinetic chain (i.e., at the knee, hip, and pelvis) may be related to aberrant alignment of the foot and ankle as well. An outline of the major issues is presented.

1. To investigate the role of foot architecture (i.e., foot type) in lower extremity biomechanics and pathologies of the feet that effect a patients ability to stand and walk in a comfortable (i.e., pain free) and safe (i.e., without falling) manner.
   - A. Objectively measure the differences in biomechanical foot function during upright posture and locomotion of individuals with different foot types (i.e., pes planus, rectus, pes casus, etc.).
   - B. Determine how these different foot types effect the function of the knee, hip, and pelvis during posture and comfortable cadence locomotion.
   - C. Examine the role of the foot, it's aberrant alignment, and supporting devices (i.e., MAFIAS, in shoe foot orthoses, splints, etc.) in geriatric postural stability.
   - D. Determine the effectiveness of foot and ankle, as well as knee, realigning devices for the treatment of osteoarthritis (OA).
     - a. Examine the clinical outcomes of these concepts applied to other forms of rheumatic disease.
   - E. Develop cost effective alternatives to the custom molded shoe for minimizing the chances of re-ulcerating as well as preventing the initial development of plantar ulcers in the diabetic foot.
2. To develop and validate quantitative tools to assist in discovering the detailed function of the foot and ankle.
   - A. Develop six degree of freedom (DF) hindfoot (i.e., ankle and subtalor joint complex) kinematics that is anatomically and hence clinically relevant for describing foot function.
   - B. Develop six (DF) based on hindfoot kinetics as well.
   - C. Extend the six DF kinematics and kinetics to the midfoot and forefoot.
   - D. Assess the static and dynamic validity of plantar pressure platform and

in shoe plantar pressure measurements.

E. Establish new reliable parameters (i.e., from 3D kinematics, 3D kinetics, plantar pressures, MRI/CT, accelerometery, etc.), to objectively define foot and ankle function during posture and locomotion (e.g., pronation, supination, internal tibial torsion, etc.).

F. Establish normative databases of these parameters and explore the potential differences offered by foot types, age and sex.

3. To determine the efficacy and effectiveness for in shoe foot orthoses to assist in the management and/or prevention of the following clinical concerns.

   A. Hallux-Abducto Valgus (HAV) - bunion deformity.
   B. Hallux-Limitus/Rigidus - first metatarsal phalangeal degenerative joint disease.
   C. Osteoarthritis (OA) and rheumatoid arthritis (RA) - foot pain, malignant and functional deficits.
   D. Plantar Faciitis/Heel Spur Syndrome.
   E. Amputation resulting ultimately from Diabetic neuropathy and/or Charcot arthropathy.
   F. Significant flat foot deformity.
   G. Lower extremity torsional deformities (e.g., foot, malleolar, tibial, and femoral).

4. Determine efficacy and effectiveness for surgical management of the aforementioned problems in their severe forms (e.g., the Evans calcaneal osteotomy for treating significant flatfoot deformity).

5. Develop improved forward dynamic foot and ankle models for computer based simulation of healthy and pathological gait.

   A. Utilize a given patients anthropometric values and gait parameters to fit the model with their data.
   B. Simulate conservative treatment of that patient with the computer based model.
   C. Make teaching versions of these models available via the Internet for general educational purposes.

John P. Holden, Ph.D.

The techniques used in gait analysis provide powerful tools to address many of the areas recently identified[1] as needing increased research in rehabilitation medicine: improving functional mobility; assessing the efficacy and outcomes of medical rehabilitation therapies and practices; developing improved assistive technology; understanding whole body system responses to physical impairments and functional changes; and developing more precise methods of measuring impairments, disabilities, and societal and functional limitations. There is justified optimism about the expanding role that movement analysis can play in rehabilitation medicine. To advance this role most effectively, progress is necessary in several key areas, including: basic research and technological developments; standardization; clinical research applications; and education and training. The six criteria suggested fifteen years ago[2] as necessary for the usefulness and widespread acceptance of any patient evaluation tool remain relevant to movement analysis today, and they can assist in motivating the formation of current recommendations. Among the many worthwhile actions that can be taken, the following are offered for particular consideration by the National Center for Medical Rehabilitation Research (NCMRR) and other agencies and organizations with an interest in movement analysis and rehabilitation medicine.

1. Recent advances in instrumentation and computer technology have greatly increased the accuracy and precision of the fundamental data collected in movement analysis, as well as the speed with which these data are processed and transformed into the information used by clinicians. Surprisingly few studies, however, have examined the effects of measurement errors, model assumptions, and data processing methods on the accuracy and precision of the eventual output variables upon which research conclusions and clinical decisions are based. As a result, researchers and clinical groups must qualify their conclusions and recommendations due to a lack of confidence in certain elements of the data. It is recommended that NCMRR and other agencies support research to document the limitations and uncertainties associated with data acquisition protocols and analysis techniques, assess their effects on the information made available for clinical interpretation, and develop new approaches that enhance the quality of movement analysis information with respect to accuracy, precision, and sensitivity.

2. Gait analysis is often used for patient assessment by comparing a patient's gait patterns with a database from able-bodied subjects, in an attempt to discriminate between "normal" and abnormal function. The normal limits defined in these databases must be sensitive enough to identify gait deviations, and to distinguish deviations which are due to primary pathological deviations, secondary compensatory phenomena, or other factors which can affect gait measures (e.g., age, gender, size, walking speed). The development of large databases from multiple centers is complicated not only by variability in subject performance, but also by variation among laboratories in how data are collected, processed, and reported. It is recommended that NCMRR and other organizations support the development of data collection

and processing standards, detailed databases that account for additional variables that affect interpretation, and data scaling techniques and statistical models that will improve the ability to accurately distinguish normal and abnormal patterns and to discriminate between possible causes of gait pattern deviations.

3. Movement analysis can provide quantitative measures of numerous parameters that cannot be assessed by other means, and these data are combined with clinical information to plan and evaluate rehabilitation interventions. Research is needed, however, to determine which variables are most important in determining a person's ability to safely and efficiently execute functional tasks. Investigations in this area should be based on a theoretical framework, or model, that will allow the results to be applied to as many activities and situations as possible. It is recommended that NCMRR support the use of movement analysis techniques for (a) basic scientific research on the roles of the various systems (e.g., sensory, cognitive, neuromuscular, musculoskeletal) that affect mobility, (b) multidisciplinary, multivariate research to measure and explain the relationships among pathologies, impairments, functional limitations, and disabilities, and (c) clinical research to validate current clinical practices, develop new tests for direct use in patient care, and test the efficacy of interventions when movement analysis is included as part of the patient assessment and/or treatment plan.

4. The full use of movement analysis to help people with locomotion disabilities requires the integration of knowledge and skills in a variety of areas, including medicine, engineering, and kinesiology. Optimal integration across these disciplines can occur when all of the people involved in the process have a basic understanding of the capabilities, benefits, and limitations of movement analysis technology. It is important that there be adequate opportunities for interdisciplinary training, as well as improved tools for efficient communication of movement analysis concepts and data. It is recommended that NCMRR and other organizations support development of new educational opportunities and approaches, including computer-based teaching tools, research training fellowships, instructional workshops in conjunction with major meetings or through tele-conferencing, and new course programs that will facilitate understanding and application of the latest information in movement analysis.

The widespread acceptance of clinical movement analysis in rehabilitation medicine may require large-scale controlled clinical trials to test the efficacy of current techniques in direct patient care. At the same time, efforts must continue in the areas of basic research, technological development, and standardization, in order to improve the quality and versatility of movement analysis as a research and clinical tool. Indeed, advances in techniques and in our basic understanding of the rehabilitation process will likely lead to more efficacious application of movement analysis in the direct clinical care of persons with locomotion disabilities.

1. *Research Plan for the National Center for Medical Rehabilitation Research*, 1993.
2. Brand R.A. & Crowninshield R.D. Comment on criteria for patient evaluation tools. *J. Biomechanics* 14(9):655, 1981.

Thomas M. Kepple, M.A.

Background:
I have worked for the last 10 years at the National Institutes of Health (NIH) Biomechanics Lab. (The NIH biomechanics lab is a part of the NIH Rehabilitation Medicine Department.) From my experience at NIH, I firmly believe that gait analysis can provide information that can be extremely valuable to the treatment of the rehabilitation patient. If this statement is true, then why are gait analysis labs rarely found in rehabilitation clinics? The failure of this potentially valuable tool to make a significant impact throughout the field of rehabilitation medicine has been the largest disappointment in my time at NIH. I believe one reason for the failure of gait analysis to make significant rehabilitation impact is that it is not cost effective to build and staff a clinical gait analysis lab. For this reason I have confined my position paper to a single issue.

Issue:
What can be done so that gait analysis can provide clinically important rehabilitation information in a cost effective manner?

Recommendations:
1) Bring down the cost of purchasing and maintaining a clinical gait analysis laboratory.

Prices of computers and technology have been dropping steadily over the past 10 years; however, these price reductions have not been reflected in the cost of the data collection systems. In addition, most gait analysis systems still require at least two full-time staff members for operation, maintenance and analysis of the data. Funding should be provided to aid in the development of high quality low cost data collection systems.

2) Improved education for rehabilitation clinicians in the area of gait analysis.

Although gait analysis provides valuable clinical information, the significance of the information is often lost in the translation between laboratory staff and practicing clinician. Improved education for the clinician will result in both better use of gait analysis data and significant savings due to the reduction of laboratory staffing.

3) Demonstrate that gait analysis can produce long-term cost benefits for the Insurance Industry.

Third party reimbursement is a major obstacle to the goal of making gait analysis commonplace in rehabilitation settings. Research must be funded to determine the areas in which gait analysis can be used to produce long-term savings for insurers.

Casey Kerrigan, M.D.

Gait laboratory analysis has not yet been recognized by third party payors as an essential tool in rehabilitation practice although there is great potential for gait laboratory analysis to become this. It is already recognized for orthopedic surgical planning in patients with cerebral palsy affecting their gait. For the same reasons that gait laboratory analysis is useful in surgical planning, it could also be extremely useful for routine rehabilitation practice. It can be used to evaluate from a dynamic perspective which particular muscle group is weak or overly active or which muscle tendon group is tight. Traditional static evaluation of muscle weakness, spasticity, and tightness is often not adequate insofar as the findings on static evaluation commonly do not correspond to findings obtained from gait laboratory analysis. This point is important since most of our rehabilitation interventions are based on accurately determining which muscle/tendon groups are functionally weak, overly active or tight. For instance, strengthening functional electrical stimulation, or bracing are prescribed to improve or substitute for strength and stretching, modalities, or nerve or motor point blocks with localized medications are prescribed to improve overactive muscle activity or range of motion. Gait laboratory analysis thus can be an essential tool in evaluating and providing recommendations for treatment in gait disability secondary not only to cerebral palsy, but to any upper motor neuron diagnosis.

Gait laboratory analysis could be useful not only for rehabilitation management, but for further rehabilitation treatment development as well. It is difficult to evaluate the effect of a particular rehabilitation intervention if the problem is not adequately assessed at the beginning and evaluated at follow-up. For instance, the effect of a functional electrical stimulation program or of a particular brace may be impossible to evaluate if the underlying weakness is not adequately assessed. Additionally, information can be obtained about the mechanism of the electrical stimulation program if gait laboratory analysis is used as an evaluation tool at follow-up. In some instances, gait laboratory evaluation may be the only manner in which to assess an impairment. For example, individuals with gait disability often have different patterns of muscle activity which can be assessed only with dynamic electromyographic evaluation. A gait laboratory evaluation may show inappropriate timing of muscle activity which can be treated with electromyographic biofeedback. Electromyographic biofeedback as a potential treatment is optimally evaluated using gait laboratory evaluations. Essentially, any treatment which aims to improve walking through improving strength, range of motion, spasticity, or timing of muscle activity is best assessed with gait laboratory evaluation. Thus, gait laboratory assessment can be an important tool in evaluating the effects of current commonly prescribed rehabilitation interventions as well as in evaluating and developing possible new interventions.

Research Recommendations:

1. There needs to be a demonstration of the benefits of gait laboratory evaluation improving rehabilitation management.

2. It needs to be shown that gait laboratory analysis provides useful clinical information which is not present per routine clinical evaluation, in particular, research demonstrating the discrepancy between static and dynamic findings is important.

3. Research is needed which develops gait laboratory analysis as an evaluation tool to assess the dynamic relevance of impairments such as strength, spasticity, range of motion, etc.

David E. Krebs, P.T., Ph.D.

Before computer aided locomotion analysis (CALA) can be accepted as a routine clinical tool, several important problems must be resolved.

Technical. There are no published studies comparing *in vivo* joints torques and forces from instrumented tendons, or joints, collected simultaneously with "gait lab" estimates of these same variable. Because power, forces and emg cannot be directly observed, CALA is attractive as a means of estimating kinetics. These estimated kinetics, however, may err in magnitude and in direction; power calculations derived from them will err as well. In contrast, modern kinematic estimates have greater validity, since at least at the gross level, they have survived repeated scrutiny by clinicians and engineers. At higher levels of precision, however, the exact joint center locations, skin movement artifacts and other errors contaminate gait analysis kinematic data, which in turn also corrupt kinetic estimates. Appropriate standards of *in vivo* precision, accuracy and validity of gait lab estimates will permit clinicians to judge the limits of CALA, much as clinicians know the resolution and limits of MRI data.

Clinical. Most rehab and surgical interventions are targeted at changing impairments. There are only 2 or 3 published articles relating gait, as a functional limitation improvement, to impairment improvement, and these gait articles used only temporodistance gait measurements. Establishment of appropriate individual, functional and normative standards must precede the widespread acceptance of, and reimbursement for, computer aided gait analysis. Most importantly, large sample intervention outcome studies are needed, to permit scientific assessment of benefits, and cost-benefits, of routine CALA. Ending the vicious cycle in which insurers under-reimburse CALA, therefore no outcomes data are produced, and therefore no reimbursement is offered -- must be a top goal.

Karen Ksiazek, M.D.

Motion analysis has most commonly been utilized kinematically document normal patterns of movement and deviations there from in individuals with disabilities. It has attempted to objectively delineate the differences invoked by treatment intervention be it surgical or fine tuning of assistive technological interfaces yet it has not been able to tell us why one form of intervention works better than another. Thus as an individual assessment tool it is unable to answer the questions of function. If incorporated with measurements directed toward kinetic and endurance evaluation, it then has the potential to impact the dynamic picture of function as it relates to functional efficiency. The parameters of kinetic assessment and ultimate workload need to be standardized before adequate valid intervention can be engendered. If kinetic approaches could be enhanced, then the change in any gait with fatigue may be explored more intensively. Resulting torque curve characteristics overtime may then shed light on the prediction of loads across muscles and the ultimate tolerable work for a given energy expenditure. In disease states this may assist treating teams to better design appropriate rehabilitative schedules and predict functional capacity for transition into the community. It could then provide a physiologic justification for varying the level of rehabilitative involvement.

Another area of great potential is in the learning of new motor control patterns those with acquired or evolving disabilities. We often find variability in learning curves and acceptance in new amputees with regards to their prostheses. Some have difficulty incorporating the prosthesis into their daily activity patterns despite extensive therapeutic intervention. If the efficiency and pattern of their motor planning could be assessed, then alterations in the interface between user and technology could be more readily directed towards the individuals needs.

Quantification of the extent of deviation from normal patterns of movement in these individuals be it gaining with a prosthesis or utilizing an artificial implant may then shed insight into the risk of developing secondary disabilities such as arthritis and scoliosis which may in the long run limit the potential gains of such prosthetic restoration. As changes may evolve overtime in functional ability or strength, motion analysis could potentially be used to assess these changes and direct updates in the prosthetic prescription to avert such secondary complications and maintain function efficiently.

Robert McAnelly, M.D.

PROBLEMS	CURRENTLY REIMBURSED GAIT ANALYSIS	REHABILITATION ISSUES FOR GAIT ANALYSIS
DIAGNOSTIC		
Number of Diagnoses	Cerebral palsy and spina bifida	CP, spina bifida, spinal cord injury, joint replacement, stroke, amputation, brain, injury, etc.
THERAPEUTIC		
Number of Interventions	Tendon and osteotomy procedures	Stretching, strengthening, neuromuscular facilitation, coordination and balance training, orthotics, prosthetics, motor point blocks, etc.
NUMBERS NEEDED		
Number of laboratories needed	One for every major metropolitan area	One for every rehabilitation unit
PERSONNEL		
Personnel available per laboratory	5-6	2-3
Level of education of laboratory personnel	Physical Therapist, MD, Ph.D. Gait Engineer, Kinesiologist	Physical Therapist, MD
FUNDING		
Funding per subject	Thousands billed for preoperative gait analysis	Hundreds billed for medical consultation and physical therapy time
Financial effect of managed care	Significant	More significant

Rehabilitation faces diverse problems. One can classify three ways to solve rehabilitation issues:

Top-down: major cerebral palsy laboratories will develop generalized gait analysis programs that will be used to analyze gait problems of multiple diagnoses. These programs will be passed down to smaller rehabilitation laboratories.

Bottom-up: individual smaller research laboratories will develop protocols for each individual rehabilitation diagnosis. A multiplicity of programs will then slowly disseminate across all laboratories.

Collaborative: Multi-laboratory studies involving small and large laboratories to share data and tackle large problems in a consistent manner. Collaborative studies are best because it draws on talent from everywhere, but laboratory standardization is an involved process.

Some solutions will evolve with better technology. Markerless systems will simplify data gathering. Expert systems will simplify analysis. Establishing therapeutic protocols will allow us to simplify marker sets. We still need to prove which diagnoses will benefit from gait analysis.

RECOMMENDATIONS

1. Help develop interlab standardization to encourage collaborative research and rapid dissemination of programming. This should include standardization of 2-dimensional gait analysis. Contact gait analysis manufactures to include them in your discussions.

2. Encourage development of movement analysis programs for upper extremity rehabilitation, back rehabilitation, and wheelchair propulsion.

Irene McClay, Ph.D., P.T.

Gait analysis has gained a healthy respect from the research arena. However, there are still many medical professionals (and insurance companies) who question the clinical merit of this tool. One argument is that it does not assist in diagnosing a condition. However, I contend that we might be able to "diagnose" the mechanics related to the condition, such as asymmetry of joint excursion. Another tenet is that gait analysis is only useful if it provides information that assists with clinical decision making. I believe that if we can gain insight into the mechanical cause of an injury, then we will be better equipped to make clinical decisions regarding optimal treatment interventions.

Therefore, I strongly believe that gait analysis could play a strong role in the clinical area. However, we need to address the following issues in order for gait analysis to be accepted as a clinical tool.

RECOMMENDATION 1

Establish normative three-dimensional biomechanical data for all forms of locomotion (i.e., walking, running, stair ascent/decent) along with the expected variability of each parameter.

The literature is generally lacking substantial normative three-dimensional data of the lower extremity during various forms of locomotion. This makes it particularly difficult to establish the presence of an abnormality in one's mechanics. Once these abnormalities are determined, relationships between structure, mechanics and injury can be established.

RECOMMENDATION 2

Establish which gait parameters are most revealing with regards to understanding a gait-related injury.

For example, angular velocities may lend more insight into a gait-related problem than peak angular values. Loading rates of ground reaction forces may be more critical than the peak values. Additionally, since joints move in concert with each other, development of new parameters describing the interaction between joints is needed. Focusing on the most critical parameters will enhance the understanding of injuries and facilitate the development of optimal treatment interventions. These critical parameters should be ones that are not readily apparent with visual gait analysis in order to justify the need for an instrumented analysis.

RECOMMENDATION 3

Investigate the effect of alteration of abnormal gait through treatment intervention.

If relationships between mechanics and injury are established, then the effect of altering those mechanics can be pursued. These interventions can take on many forms. One area of involves the active alteration of one's base of gait during running or contracting a muscle sooner during stair descent. Increasing one's available range of motion through stretching could also improve the manner in which they move. Also, the effect of orthotic intervention on gait mechanics needs further investigation. There are numerous studies on the effect of foot orthotics on foot and ankle motion. However, these orthotics are often prescribed for knee pain and their effects at this joint are still unknown. This information is helpful, not only to the clinician, but also to insurance companies who need objective outcome measures to establish the efficacy of the treatments for which they are reimbursing.

In summary, I believe the time has come to provide evidence of the merit of gait analysis in the clinical arena. Its utility in assisting in clinical decision-making and determining efficacy of treatments through outcome measures must be proven. Cost-benefit analyses must be performed. These steps are needed before it will become accepted by the medical and the insurance communities. The working conference on gait is the first step in this process and I look forward to the opportunity to participate in this important meeting.

Ellen H. Melis, M.Sc.

My experience in gait analysis stems from my Master's training in Rehabilitation Sciences at McGill University, where I worked with spinal cord injured subjects receiving FES-assisted gait training. I have also worked in the area of elderly gait and am presently involved with spinal cord injured subjects walking with ambulatory assistive devices. My affiliation with the Rehabilitation Institute and their Gait and Motion Analysis Laboratory puts me in contact with the clinical setting as well as the research environment.

I believe that many clinicians presently do not have access to gait analysis, partly due to the fact that many of the gait analyses are expensive. I also believe that many clinicians do not receive the proper training to interpret the data one would be able to obtain from a proper gait analysis. The education of clinicians is an area which should be addressed. The proper interpretation of data is highly important if the use of gait analysis is to be meaningful. Furthermore, I think there should be normative data to which slow gait patterns (as often seen in rehabilitation candidates) can be compared. We are in the final stages of preparation of such a study. I also feel that the reporting of gait analysis should be standardized so that clinicians can communicate in the same language. EMG data for example is often normalized to peak EMG, but other times to average EMG level. These issues should be addressed if gait analyses in rehabilitation are to be meaningful.

In order to advance the area therefore, I would suggest that the following topics be addressed:

1) The training of clinicians at the professional level as well as the undergraduate and graduate level.

2) The availability of EMG analysis systems and access to these systems from the clinician's point of view.

3) General guidelines for the normalization of gait data.

4) Normative data should be collected for comparative speeds for subjects without disabilities.

Freeman Miller, M.D.

The current definition of the application of gait analysis to clinical medicine should be clarified by a position statement with respect to what people are doing and what parts of clinical medicine gait analysis is currently accepted clinical practice. I think there are specifically some areas that are fairly clear, such as in the treatment of cerebral palsy. There are other areas where there is come what less experimental applications in clinical medicine. Getting some definition of where gait analysis is in its current application to clinical medicine would be a useful statement for people planning the formation of laboratories at the level of hospitals.

There is a need for research agencies especially funding agencies such as the NIH and private funding agencies to have a sense of where in the area of development gait analysis laboratories currently are. Again, in this area it is my feeling that gait analysis development is far enough advanced that this is really in the realm of the commercial state and that commercial companies should be encouraged to continue this development. Except for some rare exceptions, this should not be a current area of federally funded research. Also there is such a wide clinical application that gait laboratories should largely be planned and funded by hospitals and other care providers as a part of their provisions of clinical services with those services being paid for by the patient or their third party payers. This kind of infrastructure spending I also do not feel should be part of federal funding.

There clearly are areas of research which would encourage gait analysis to grow and encourage its more rational application. Specifically, I feel that some federal funding directed at understanding how to use gait analysis for outcome research and funding directed at fostering communication and developing ways for data sharing so that larger groups of patients can be identified to evaluate outcome research is something that should be encouraged. The understanding of how technical outcomes as measured by gait analysis are reflected in the patient's overall functional outcome also needs to be evaluated.

We need to define a list of problems that are currently addressed by clinical gait laboratories in the area of what is preventing them from functioning best for patients. Some of these which I have experienced are a lack of trained personnel which is especially true of physicians understanding gait analysis techniques, a lack of standardization in gait analysis and gait analysis laboratories, still the continuing struggle to obtain funding from third party payers because they do not understand the technology, and the reluctance for investment by hospitals and other clinical care providers into this technology.

Don W. Morgan, Ph.D.

A major issue in gait analyses in rehabilitation medicine is the use of exercise as a tool in the assessment and management of gait-related disorders in children with neuromuscular disease (NMD). Issues deserving of further attention include the development and refinement of testing protocols to assess muscle strength and function, quantifying the relationship between changes in muscle strength and function and gait parameters, and determining the extent to which various exercise training stimuli improve locomotor efficiency and performance.

With respect to exercise testing of children with NMD, variables which have clinical and functional importance include muscle strength and power. Muscle strength is often reduced in pediatric NMD and may progressively decrease with physical growth. Since certain disease conditions feature joint contractures and varying rates of strength decrements, modifications in muscle strength testing protocols may be required. Levels of muscle endurance, peak mechanical power, and total mechanical work are also lower in children with NMD compared to age-matched controls. Interestingly, few studies have been conducted examining the association between muscle strength improvements and gait function in the child with NMD.

Another physiological variable that has clinical relevance for the child with NMD is the energy cost of locomotion. Limited data in children suggest that the aerobic cost of transport is substantially higher in children with cerebral palsy (CP) compared to normals. While the factors explaining this phenomenon remain obscure, it is likely that specific temporal, kinematic, and kinetic features of gait may contribute to energy-inefficient locomotion. From a practical standpoint, a wasteful gait pattern may restrict the functional and physical capabilities of young CP children to varying degrees, thus limiting their physical independence and their integration into school, recreational, and family activities.

Based on the aforementioned discussion, a number of future research directions emerge that would have meaningful implications for clinicians. Alternative exercise testing protocols for children may need to be developed to assess levels of muscle strength and locomotor efficiency in NMD children and of muscle strength and locomotor efficiency in NMD children and to track the relationship between changes in these variables and alterations in gait. The development of age-appropriate databases on normal children can also serve as a benchmark in establishing realistic goals for locomotor energy demands and gait performance in young CP children and provide an informed basis for the early evaluation and rehabilitation of this cohort. Such an approach might be expected to increase the likelihood of achieving near-normal or satisfactory levels of functioning in children with CP, while minimizing the long-term physical and economical consequences associated with this health condition. Lastly, more research is needed to assess the neuromuscular trainability of the child with NMD. While it has been suggested that exercise training can enhance motor independence and walking performance in NMD children, experimental support across a wide variety of NMD conditions is sparse. Along these lines, additional study should be conducted to document the therapeutic use of strength training and augmented gait and EMG biofeedback to drive specific features of the gait pattern toward more optimal conditions. Although speculative, such an approach might improve locomotor efficiency and reduce the need for surgical intervention.

Michael J. Mueller, Ph.D., P.T.

There are many areas where research is needed to improve the effectiveness of Gait Analyses in Rehabilitation Medicine. I believe the following recommendations are some of the most important.

1. Research is needed to determine how to use gait analysis to help make clinical decisions and guide treatment. To achieve this goal, we need to understand better the relationships between measures of impairment, function, and disability as they relate to walking. For example, the traditional rehabilitation model has assumed that reductions in muscle strength and range of motion (ROM) can cause deficits in walking resulting in reduced mobility in the patient's given environment. Treatment is directed at improving the impairments, i.e., increasing the strength and ROM, to improve the patient's ability to walk. Research is needed to clarify these relationships and determine optimal methods to improve walking and related disability.

2. Research is needed to understand Fitness better the strategies that patients use to walk given various musculoskeletal and neurological impairments. Musculoskeletal and neurological impairments can be thought of as various constraints that the patient must work under. A greater understanding of optimal strategies for specific impairments would help the rehabilitation team to treat patients to overcome or compensate for any given impairment. Treatment may include exercise, gait training, surgery, or adaptive equipment.

In regard to determining these optimal "strategies," theories from Motor Control and Biomechanics should be integrated and applied to gait analysis and training. Kinetic gait analysis variables, such as joint movements and power, should be characterized further in various patient populations to identify common patterns. The kinetic variables may provide further insights to the causes of movement patterns and implications for most effective treatment interventions.

3. Research is needed to identify how technology can benefit gait analysis and treatment. Further work is needed to clarify how technology, such as imaging (i.e., CT scans), pressure sensors, finite element analysis, and gait analysis, can be integrated in the design and fabrication of orthotic, prosthetic, and other assistive devices to enhance walking.

Sara Mulroy, Ph.D., P.T.

All aspects of health care are facing a similar challenge: to substantiate, using outcomes and cost data, that the services provided are not only effective but also cost efficient. Rehabilitation medicine has the additional handicap of not providing an immediate, life-saving service. The benefits of rehabilitation therefore, are harder to quantify than those of acute care or emergency medicine and often are judged to be a luxury.

Gait analysis traditionally has been labor intensive and expensive. To survive in the current climate of minimalist health care, gait analysis laboratories must identify the information that they provide that impacts both cost and patient outcomes. The most common clinical use of a gait analysis laboratory is a pre-surgical evaluation. If a gait evaluation can identify which surgeries are most likely to be successful and which ones are not appropriate, those patients who do have surgeries should have better outcomes and those who do not should have avoided the unnecessary medical expenses.

The interpretation of the data and the decision-making process, however, are not standardized across laboratories. There are two major approaches to surgical recommendations based on gait analysis data. Both methods use motion analysis data to pinpoint the primary gait deviations, but one approach identifies the muscular causes and contributors with EMG data (indwelling, fine-wire, electrodes) and a second approach uses kinetic analysis to document the net internal moment required to meet the demands at each joint. In the second example EMG data typically are collected with surface electrodes and are used only as secondary, supporting information.

A multi-center study is needed to evaluate patient outcomes and cost data of post-surgical patients who had their surgical decision based on fine wire EMG data and those based on joint kinetics with supporting surface EMG data compared to the outcomes of patients who have surgery without a pre-operative gait analysis. Laboratories representing both perspectives should collaborate on the project. A cost-benefit analysis could identify a minimal data set necessary for accurate pre-operative assessment and allow patients and providers to select a level of pre-surgical evaluation based on the knowledge of predicted outcomes gained with each additional procedure or piece of information. This study should focus on a variety of patient populations, both pediatric and adult.

The second role of gait analysis laboratories in rehabilitation medicine is to provide information that directs patient treatment and identifies the optimal use of scarce rehabilitation resources. This can take three forms: testing of individual patients under several treatment conditions, comparing therapeutic approaches for groups of patients using and experimental design and identifying gait variables that when measured on an individual predict whether a particular treatment would be appropriate.

Gait analysis laboratories also are uniquely equipped to evaluate the biomechanics of functional activities other than walking such as wheelchair propulsion, transfers and upper extremity activities of daily living. Documentation of suboptimal movement or patterns of muscle use could extend the scope of gait analysis laboratories' contribution to patient care.

My recommendations to advance the role of gait analysis in rehabilitation medicine are:

1. Conduct a multi-center study to document cost and post-surgical outcomes with and without pre-operative gait analysis for a variety of patient populations.

2. Compare the outcomes of surgeries in which the plan was based primarily on EMG data with those based on joint kinetics.

3. Delineate the accuracy and reliability of surface and fine wire EMG in pre-surgical decision-making.

4. Support therapeutic intervention studies designed to identify factors that predict successful outcomes or which therapeutic approach would be most appropriate.

5. Collaborate with clinicians to investigate pathological biomechanics in upper-extremity functions and activities other than ambulation.

Jennifer Nymark, M.Sc.

Gait and motion analysis facility has the potential to be a strong evaluative tool in clinical rehabilitation to identify, classify and monitor outcome of functional movement limitations due to a variety of impairments. However, the gap between academic laboratory research and clinical practice continues to exist. Consequently, the Gait and Motion Analysis Laboratory was developed at our adult rehabilitation center and supported as an integral part of clinical service to foster evidence-based clinical decision-making in addition to its research mandate. The team is comprised of physical therapists, rehabilitation engineers, research kinesiologist, electronic and mechanical technologists and physiatrists. All personnel have a proportion of their positions dedicated to the Laboratory in addition to their other clinical and research activities. Clinical referrals representing a wide variety of impairments, diagnoses and age groups are received from internal staff and external clinicians.

Major Issues: The following issues are drawn from our experience and communication network of peers and are highlighted under 3 main categories: 1) Administrative and Academic Support 2) Standardization and 3) Quality and Cost of Health Care.

Administrative Support

Dedicated physical space and trained human resources are still a rarity in clinical institutions. A comprehensive resource list of all clinical service laboratories world-wide, within or close to clinical settings, would be of great benefit for information sharing and added evidence for continued support from hospital administrators. Formal joint-university appointments and academic collaborators are essential to the development of our clinical facility.

Standards of Procedures and Interpretation of Data

More formal training and support is required to standardize measurement procedures and interpretation of results particularly in the area of 3 D kinematics, kinetics and EMG processing and quantification. Normal or appropriate data bases are still limited and need to be developed further in order to assist in our interpretation of data particularly in the older and the substantially slower walking clients. Laboratory reports need to clearly indicate the specific deficits in order that meaningful information will answer the questions posed by the referrants.

Quality and Cost of Health Care

Clinical gait and movement analyses are often time-intensive and require specialized training of personnel. The challenges to the emerging technologies are to improve the user-friendliness and turn-around time for data display. Clients, referrants and evaluators would all benefit from less complex systems. At present, it would seem critical to have all clinical laboratories document and share findings with their peers on concrete examples of cost-benefit analyses related to the delivery of rehabilitation care.

SUGGESTED GOALS OF THE CONFERENCE

1) Generate a mechanism for a world-wide network communication of a) clinical and b) research, gait and motion analysis laboratories for sharing and comparing information

2) Obtain agreement on the need and mechanism to initiate standardization of evaluation procedures and interpretation of results

3) Gain support on the need for more published investigations on cost-benefit analyses of clinical gait and motion analysis service in rehabilitation

4) Profile the need for more formally recognized post-graduate education programs in this field

5) Gain support on the need for the formation of guidelines to assist referrants to gain the most useful information from a referral to a gait and motion analysis facility.

Carol A. Oatis, P.T., Ph.D.

The central issue in gait analysis in rehabilitation medicine is the question of clinical relevance. As we all know gait analysis fell into disrepute in the late seventies because there was little apparent clinical benefit from the elaborate analyses performed on patients. While there was some benefit in situations where EMG was used to help guide surgical decisions, most clinical decisions were unaffected by the gait analysis. In fact, the gait data frequently arrived at the clinician's desk weeks after the patient was gone.

Gait data are now more quickly available to the clinician, but I still believe that we must more clearly identify the benefits of sophisticated gait analysis to the patient and clinician. Will the assessment provide data otherwise unavailable and, more importantly, will these data affect the way the patient is treated. The rapidly changing health care environment demands that there be a better accounting of the application of costly evaluations. One of the ways to answer these questions is to ask more questions relating gait data to more relevant functional activities and to the patient's self perceived function. The ability to walk in a well-lit laboratory may not correlate with an individual's ability to walk at home or in the community.

Another related issue is the accessibility of gait analysis to the patient population. Clearly the vast majority of patients do not have access to sophisticated gait analysis. However one might ask whether all patients need this detailed evaluation. As the question of clinical relevance is better understood, a clearer image of what types of patients will benefit should also emerge. Classification of gait disabilities may lead to a better use of gait analysis technology.

In summary, I believe that the primary issues related to gait analysis and rehabilitation medicine are those addressing the medical gains and the economic costs of this approach for the majority of patients.

Susan Rethlefsen, P.T.

Gait analysis has made great strides in recent years in terms of the equipment and software used, increases in the types of information which can be obtained (i.e., kinetic data), as well as improved education for clinicians interpreting gait analysis data. However, as our skills and technology have advanced, new problems and issues have arisen. Some of these relate to gait analysis models and methodology, others deal with the interpretation of data as well as expanding the application of motion analysis technology.

1. One technical problem involves the limited applicability of some kinematic models to subjects with certain types of bony deformities, such as pelvic obliquity, subluxed or dislocated hips, extreme equinovarus or Plano-valgus deformities at the ankle, as well as torsional problems in the femur or tibia. The models used in data processing software are developed based on subjects with normal anatomy, and can yield inaccurate information in some types of patients.
Recommendation: Continue refinements in existing models so that they can be applied to subjects with the above problems.

2. It is a goal of many gait laboratories throughout the country to conduct multi-center research. Yet inconsistencies exist in the equipment and methodology (such as marker placement, EMG normalization techniques and software used to process the data) employed by different laboratories, making this impossible.
Recommendation: Standardization of procedures and methodology among gait labs, as well as studies to determine ways to improve reliability and validity of data collected both within and among different laboratories so that data can be shared.

3. Gait analysis is most often used in pre-surgical planning, and to assess the outcome of surgical procedures. There is a limited amount of research in the literature regarding the outcome of other interventions to improve function, such as serial casting, functional electrical stimulation, strengthening programs, etc. on gait and function. Gait analysis is an excellent tool for examining the impact of these alternative treatments.
Recommendation: Research on the outcome of alternative therapeutic treatments on gait and function.

4. Surgeries done based on gait analysis data lead to a more “normal” looking gait pattern on the data plots and graphs. However, walking velocity often decreases after surgery, and other functional skills sometimes become impaired (such as sitting on the floor, getting up from the floor, getting in and out of the bath tub). Gait is only one aspect of gross motor function, and information regarding the effect of surgical intervention on other functional activities is needed.
Recommendation: Encourage study of gross motor functional skills (in addition to gait) in patients before and after treatment intervention.

Cheryl Riegger-Krugh, ScD, P.T.

Gait analysis adds a great deal to the evaluation of movement ability for patients with neuromusculoskeletal dysfunction. Gait analysis includes a wide-range of visual of observational gait analysis to very instrumented measurement of a person's gait. The term "clinical gait analysis" has different operational definitions for different people.

Recommendations of high priority for gait analysis:

1) Clarify the term "clinical gait analysis."

2) Develop gait outcome measures that are predictive of future functional mobility status.

3) Determine the meaningful gait outcomes measures that are able to be identified with visual gait analysis. These measures may require validation with instrumentation.

Mary Rodgers, Ph.D., P.T.

A number of issues have prevented the wide-spread acceptance of gait analysis results in Rehabilitation Medicine. The usefulness of gait analysis assessments in treatment planning and/or treatment implementation is dependent upon having timely and accurate results which are presented in a summarized and understandable fashion. The technologies involved are relatively new and varied, so that research work going into gait is ongoing. This presents difficulty with normative comparisons because of lack of large data collections and inconsistency of instrumentation. Also, the compensations required by some individuals who have pathologies may allow a functional, although not normal, gait. So another issue becomes what the desired outcome is for the wide variety of pathological gaits, especially if “normal” gait is not the target.

Katherine Rudolph, M.S., P.T.

Computerized Clinical Movement Analysis Position Statement

Computerized movement analysis is currently being used by a wide variety of individuals and institutions for anything from research to clinical decision-making. Some laboratories serve both functions. In the current health care environment, technologies are being developed in order to provide more appropriate and effective treatments. Movement analysis laboratories are growing in numbers and the information they provide can be a valuable complement to other medical information, however, I feel that as a profession we need to consider the future very carefully.

One prominent problem that needs to be addressed is that of third party payer reimbursement of computerized movement analysis. Anyone who has seen a child with cerebral palsy, who is unable to walk following many inappropriate surgeries can attest to the need for gait analysis in surgical planning in individuals with cerebral palsy. However, many third party payers are unaware of the efficacy of such testing because the literature is lacking in well-designed studies which show its benefit. I feel that research funds should be provided to perform prospective studies in the field of gait analysis in people with cerebral palsy as well as the use of movement analysis in other populations. Once this is done, computerized movement analysis in populations where its value is well established will be covered by third party payers and movement analysis laboratories can begin to move into other areas in which its use could be vital, such as analysis of movement for treatment planning in physical or occupational therapy.

Another important aspect of movement analysis is the lack of clearly defined guidelines for the proper use of motion analysis technology. Laboratories may have different measurement techniques which provide similar information, for example, the use of three dimensional electrogoniometers for recording joint kinematics as opposed to three dimensional video based movement analysis systems. Some of the technology is appropriate, others may not be. Until the efficacy of one technique over another, or proof that two techniques are equivalent, is shown it will be difficult to ask third party payers to reimburse for computerized gait analysis. This would also aid in assigning standardized movement analysis codes for reimbursement.

Clinical movement analysis laboratories are typically staffed by individuals from diverse backgrounds, including medicine, physical therapy, biomechanics, and engineering. These individuals are often trained under "experts" in the field, through on the job training or continuing education courses. While this type of training can be very extensive, it is not standardized in any way. The multi-disciplinary aspect of this type of team provides a wide-range of input into the day-to-day functions of the lab. However, because of the diversity of training it is of the utmost importance that we show the public and third party payers that every lab is qualified to perform computerized movement analysis. This does not preclude others from performing movement analysis for research purposes, it merely ensures that the public is getting a clinically useful and appropriate test.

To further this cause, I feel that a minimum level of competency should be demonstrated, through licensing, by all individuals involved in the *analysis* of gait data, including therapists, physicians and others who would be interpreting motion data. Training should be performed by laboratories, designated as being training centers. This licensure would ensure that the personnel are qualified to chose and perform appropriate tests and that they are qualified to make appropriate interpretations of the information. I also feel that each clinical motion analysis laboratory should also be licensed. This licensure would include demonstration of a standard level of accuracy, reliability and validity with their measurement systems.

Finally, I feel that although the issues facing the movement analysis community are numerous many of them impact each other. I feel that we are all committed to furthering the advancement of clinical movement analysis and I feel that this working conference has allowed many individuals, from different disciplines, to define a direction for the near future of this clinical tool. I propose that conferences such as this be repeated periodically, to set goals and assess the progress of our mission.

Lisa M. Schutte, Ph.D.

Major issues facing the field of gait analysis include ensuring that the best possible quality of data comes out of the clinical gait analysis labs and that the treatment decisions made using the data have scientific basis whenever possible. The discussions concerning standards and accreditation started by groups such as the American Academy of Cerebral Palsy and Developmental Medicine and North American Society of Gait and Clinical Movement Analysis are an important step in addressing both issues. In addition, the current accepted practices of clinical labs can always be improved upon. Future methodological and technical advances should be aimed specifically at increasing the reliability of the data generated by the clinical labs. For example, data quality can be improved by methodological improvements that decrease the dependence of data quality on precise marker placement and technological advancements that decrease the encumbrance of patients during data collection may allow the patients walking pattern in the lab to more closely match their functional abilities in the community.

Ensuring that good clinical decisions are made based on the gait data is difficult. A great deal of information is gathered in a typical gait analysis. How that information is interpreted depends heavily on the experience and intuition of the clinicians looking at the data. In general, gait analysis provides a good assessment of what a particular patient's gait looks like and how it differs from normal but still does not necessarily provide much direct information about why the gait is abnormal. Answers to questions such as: What underlying pathologies are causing the gait deviations? Which gait deviations are compensatory mechanisms and which are directly causes by pathology? Are not always obvious. Consider, for example, crouch gait (i.e., excessive knee flexion throughout stance) a common gait pathology in children with cerebral palsy. Many different factors are thought to contribute to crouch gait (i.e., hamstrings tightness, hip flexion contractures, weak ankle plantarflexors, poor balance). Gait analysis not only provides a way to quantify the amount of excess knee flexion but also provides a way to tell if the hip is flexed, internally rotated or abducted more than normal, if the pelvis is tilted forward or backwards or if the EMG of any muscles is abnormal. All this information may impact treatment decisions. However, there remains no consensus on how to distinguish between the various potential causes of crouch gait. Additional research aimed at increasing our understanding of the relationship between specific gait deviations and the causative pathologies is necessary in order to adequately address such issues. In my opinion this research should be a combination of well-designed clinical studies and more basic research into the mechanics of normal and pathological gait.

The lack of universal acceptance of gait analysis is a major factor that prevents people with locomotion disabilities from accessing gait analysis. Although gait analysis has many strong advocates and acceptance has increased in recent years, many third party payers and potential referring physicians remain skeptical. For gait analysis to be widely accepted additional outcomes based research is needed to establish the utility and reliability of gait analysis in identifying when specific pathologies are contributing to a patient's gait abnormalities. That is studies must demonstrate that for specific groups of patients gait analysis provides a reliable means to choose between two or more potential treatments and properly choosing between these treatment results in improved outcome.

Acceptance of gait analysis is also limited by the complexity of the information that is collected in a typical gait analysis and by the difficulties associated with communicating this complex information to nonexperts. Technological advances in telecommunications, computer graphics, multi-media have great potential to impact how gait analysis data is stored, communicated, and shared, and how individuals are educated about gait. These technological advances should be utilized intelligently by people working in the field of gait analysis to make gait analysis information more accessible.

In summary, my specific recommendations for the field of clinical gait analysis are to:

1. Continue efforts to establish a formal accreditation process for clinical labs.

2. Continue to develop more reliable and less cumbersome methodologies and tools for data collection.

3. Conduct both clinical and basic research aimed at increasing our understanding of the relationship between specific pathologies and observed gait abnormalities.

4. Conduct clinical, outcomes based research to establish utility of gait analysis in selecting appropriate treatment for individual patients.

5. Effectively utilize technological advances in telecommunication, multi-media, computer graphics to better communicate information about gait to non-experts.

Karen Lohmann Siegel, M.A., P.T.

Issue #1: Identify critical impairments that lead to locomotion disability.

Background: Rehabilitation clinicians frequently need to develop treatment plans for individuals with locomotion disabilities who have numerous physical impairments and functional limitations. As a result, rehabilitation goals must be prioritized, along with the treatment approaches designed to meet those goals. Rehabilitation treatment plans often focus on physical impairments, with the hope that minimizing impairments will minimize locomotion disability. Prioritization often assigns greater importance to treatments designed to ameliorate the most severe impairments, but there is no certainty that the greatest impairment is the greatest contributor to a locomotion disability. A casual relationship between specific physical impairments and locomotion disabilities has not been well established. If thresholds for levels of impairment could be identified that predict a greater likelihood of locomotion disability, it would provide clinicians with objective information on which to develop goals with their clients and prioritize treatment plans. In the case of chronic progressive disorders with increasing severity and number of impairments over time, these thresholds could help to identify critical periods when rehabilitation intervention is essential to maintain ambulation ability.

Recommendation: Research employing gait analysis methodologies is needed to identify the critical impairments that are most likely to result in functional gait limitations (so that clinicians can appropriately prioritize rehabilitation treatment plans) and should answer the following questions:

a) What is the relationship between typical physical impairments, functional gait limitations, and locomotion disabilities?

b) Specifically, what is the critical location and severity of pain, excursion of each lower extremity joint, strength of each lower extremity muscle, coordination, proprioception, metabolic capacity, and other abilities that are needed to prevent functional gait limitations and locomotion disability?

Issue #2: Develop criteria for ideal compensatory gait patterns for a given set of impairments.

Background: Normal gait patterns are the current "gold standard" to judge success in the rehabilitation of people with locomotion disabilities. However, symptoms of overuse are common in relatively unimpaired structures that attempt to compensate for impaired structures. As a result, "normal" gait patterns may not be optimal for many individuals with functional limitations in gait. Rehabilitation clinicians need guidelines to determine what is an optimal compensatory gait pattern for a given set of impairments to assist in goal setting with their clients and in developing treatment plans.

Recommendation: Research employing gait analysis methodologies is needed to identify the best goal of rehabilitation for locomotion disabilities by answering the following questions:

a) What are the compensatory gait strategies utilized by people with locomotion disabilities for a given set of impairments (such as those commonly associated with amputation, hemiparesis, spastic diplegia cerebral palsy, neuropathy associated with a specific peripheral nerve or spinal level, muscle disorders affecting specific muscle groups, and others)?

b) Do some compensatory strategies result in better gait function than others (such as fewer falls, faster walking speed, increased walking endurance, and other measures) for a given set of impairments?

c) Are some compensatory gait strategies more likely to produce symptoms of overuse (such as pain, muscle strain, joint instability, or other symptoms) than other compensatory gait strategies for a given set of impairments?

d) Based on the answers to the above questions, what is the optimal compensatory strategy in gait for a person with locomotion disability associated with a given set of impairments?

Issue #3: Establish how the results of gait analysis can be used to develop rehabilitation treatment recommendations.

Background: The results of gait analysis have been used to assist in the development of rehabilitation treatment recommendations for individuals with locomotion disabilities. The indicators for various rehabilitation treatment components and the mechanisms by which the treatment affect gait have not been well documented through research. As a result, the interpretation of gait analysis data and the process by which recommendations are developed is heavily dependent upon the professionals performing the gait evaluation.

Recommendation: Research is needed to establish the indications for rehabilitation treatment recommendations from the results of gait analysis based on an individual's existing physical impairments, functional gait limitations, and locomotion, and locomotion disability by answering the following questions:

a) In the area of exercise:
What are the indications for various types of exercise and for which muscles should they be prescribed?

b) In the area of gait training:

What gait devices (if any) should be prescribed and how should they be utilized? What compensatory gait strategies should be encouraged, and what compensatory strategies discouraged? What is the best way to teach an individual to utilize the desired compensation?

c) In the area of footwear:
What is the optimal shoe design? What shoe modifications are indicated and how should they be designed?

d) In the area of orthosis prescription:
What type of orthosis is indicated (foot, ankle-foot, knee-ankle-foot, etc)? What are the best characteristics for the orthosis components (flexible or rigid; articulated or locked joints, etc.)?

e) In the area of prosthesis prescription:
What are the best characteristics for the prosthesis components (type of foot, type of knee joint, alignment, etc.)?

Issue #4: Document the role of gait analysis in rehabilitation treatment.

Background: There is an anecdotal case evidence to suggest that the results of a gait analysis can be used to guide rehabilitation treatment planning and improve walking ability of people with locomotion disabilities. However, the contribution of gait analysis to the rehabilitation process and its potential benefit has not been systematically documented in an adequate number of research studies.

Recommendation: Controlled randomized research studies are needed to document the potential impact of gait analysis on the rehabilitation process of people with locomotion disabilities to answer the following questions:

a) Do the results and conclusions of gait analysis change rehabilitation treatment plans?

b) Is functional level at discharge from rehabilitation treatment greater in individuals who have undergone gait analysis for the purpose of making rehabilitation treatment recommendations when those treatment recommendations have been implemented?

c) If rehabilitation treatment plans developed from gait analysis provide individuals with a higher functional level than rehabilitation without gait analysis, what is the impact of the higher functional level on the health, productivity, independence, and quality of life of the person?

Lisa Selby-Silverstein, Ph.D., P.T., NCS

The following are my recommendations with respect to advancing the field of Gait and Motion Analysis in Rehabilitation Medicine:

1) Clinicians need to be educated as to strengths, limitations, and utility of various components of gait and motion analysis and *the variety of populations* which might benefit from their utility.

2) Manufacturers need to be held accountable to have their systems attain a particular level of performance and they should disclose all strengths *and limitations* of their systems in a clear format in the sales literature.

3) Billing and reimbursement needs to be available for subjects with a variety of diagnostic codes. Billing should be based on what is done (not just "gait analysis" but rather 4 channels of EMG, 2D or 3D motion analysis - possibly by number of frames?) and depth of the analysis. Payment should be approved or disapproved based on impairment *NOT DIAGNOSIS*. For example, this type of analysis should be reimbursable for any patient with a balance, gait, or movement impairment which needs to be understood, documented or tracked by quantitative means. Reimbursement should not be just for children with cerebral palsy before and after surgery. Perhaps with more detailed understanding and tracking of movement disorders, recommendations for treatment interventions such as physical therapy or pharmacological management could be based on more objective findings. In addition, their efficacy could also be monitored.

4) We must assure that standardization does not limit use and/or growth of the field of motion analysis (or reimbursement thereof). Use of quantitative measures should be encouraged by all groups of clinicians treating movement dysfunction.

5) Any type of clinician licensed to evaluate and treat movement dysfunction should be encouraged and reimbursed for the use of quantitative measures to assist in this process. This should include any of the measures used in motion analysis. Collaboration with technical personnel should be required for laboratory development, up keep, and data interpretation. In addition, since I believe that any one clinician will tend to make recommendations biased toward treatments they know best, teams of clinicians probably would make the best recommendations. I believe that when clinicians make treatment recommendations, they should only make them within their licensure pervue and expertise as aneurologist, physiatrist, orthopaedist or physical therapist. Hence, particular situations might warrant interpretation and recommendations be made by teams of clinicians and technical personnel familiar with motion analysis *as well as management options* for the pathology of interest. Unlicensed or unregistered technical personnel should definitely assist in understanding and interpreting gait data, but should not make specific treatment recommendations.

Guy Simoneau, Ph.D., P.T.

My particular interest in gait analysis revolves around its use in the rehabilitation of older individuals who have ambulation and/or balance disorders. The major issue is determining whether gait analysis can in fact provide objective information, not available through a typical physical examination, that would influence the treatment procedures and ultimately the rehabilitation outcome of these individuals. This evidence (perhaps) with the exception of gait analysis in the pediatric population) is currently lacking in the literature.

Recommendations:

1) To develop a body of literature demonstrating the usefulness of gait analysis for clinical decision-making in adult patients with orthopedic/balance disorders. For example: produce controlled studies comparing rehabilitation recommendations made based on the physical examination alone compared to the treatment recommendations made from the physical examination supplemented by the biomechanical evaluation. Ultimately, these studies would help determine whether these differences in recommendations (assuming there would be differences) actually have a positive effect in rehabilitation outcome.

2) Based on the above studies, identify the components of the biomechanical evaluation that are useful: kinematics, kinetics, GRF, momentum, EMG, etc.

3) Develop consistency across labs for the evaluation procedure, the interpretation of data, the generation of reports and cost.

Jean L. Stout, MS, P.T.

The ability to regain or retain walking ability after the onset or diagnosis of a motor impairment is a major goal of the rehabilitation process. In gait analysis we have technology that can describe, quantify, and advance the understanding of how walking occurs, what happens when walking is disrupted, and in some cases, what treatment is needed for walking to be restored for optimal function. Clinically, gait analysis can provide an objective measure to assist in treatment planning, and provide and objective measure of the outcome of the treatment and the rehabilitation process involved in that treatment. And yet, during a time when outcome data and research is encouraged and sometimes demanded by payors of treatment, the use of gait analysis is not considered a necessity for determination of treatment planning to treatment success in the improvement of walking.

The issues which inhibit the use of gait analysis in rehabilitation medicine as the powerful tool I believe it is, come from a variety of sources. These include:

- Lack of access of Patients with Locomotor disabilities to Gait Analysis: This occurs by lack of reimbursement of third party payors who consider gait analysis to be experimental and by professional colleagues who treat gait disorders but consider gait analysis to be unnecessary. Education of both professionals, third party payors and the health care consumer falls into this category.

-An Under developed Potential of Gait Analysis as a Diagnostic and Prognostic Tool: Lack of and appropriate neurophysiology ---> engineering interface underlies this problem. Improved correlations between basic science knowledge of the pathophysiology of the disorders and the effects on the motor output need to be established. Current engineering models fail to adequately incorporate pathologic neurophysiology. Characteristics of the locomotor disabilities need to be better understood.

- Limitations Imposed by Current Technology and Instrumentation: Improvements would enhance the usefulness of gait analysis information in rehabilitation therapy programs. Functional measures of muscle strength, dynamic balance, and energy sources are examples.

-Lack of Standardization Among Existing Laboratories: When a health care professional recommends or orders an MRI or a diagnostic EMG and Nerve Conduction studies, results are typically reported in a standardized fashion that is not dependent upon where the study was conducted. This, unfortunately, is not the case in the area of gait analysis. Standardization of protocols and output need to be established. Just as MRI scans are read by specialists with certain qualifications for understanding the output from the study, the field of gait analysis also needs to develop qualification standards for those who interpret data.

- Lack of Correlation of Gait Analysis Information and Current Rehabilitation Procedures: This broad area incorporates rehab therapy protocols for treatment, standard diagnostic EMG, prosthetic designs at various levels of amputation, orthotics, etc.

I believe that the NCMRR model of outcome research can be applied to the area of locomotor disorders and the enhancement of function through the use of gait analysis. Understanding the pathophysiology, impairment, functional limitations, disability, and societal limitations are all vital. Recommendations related to the above problem areas would be as follows (these are not listed by priority):

1) Promotion of studies to Document the Effectiveness of Gait Analysis as a Clinical Outcome Tool. These studies should emphasize the correlation of the results of functional activities of locomotion including balance, speed , energy expenditure, etc.

2) Develop a Stronger Neurophysiology ---> Engineering Interface to understand the role of neuropathology and/or muscle pathology to the effects on gait and gait analysis information. This should include but not be limited to areas of pattern recognition, improved neuropathological engineering models of gait, defining standard patterns of pathology for particular disorders, and models to restore function in lower motor neuron injury.

3) Promote research to define the prognostic indicators within gait analysis data for potential functional improvement after surgical intervention.

4) Promote advancement of current instrumentation to assess more aspects of gait.

5) Develop guidelines or definition of required or desired areas of assessment by clinical gait analysis to be as inclusive as possible to all aspects that define dysfunction.

6) Promote the development of medical education models that incorporate gait analysis as the definitive procedure for identification, definition, and treatment planning of all locomotor impairments. These education models should include health care professionals, third party payors, and health care consumers.

Duk Hyun Sung, M.D. and Jongmin Lee, M.D.

First of all, there is no established standard methodology to run gait analysis system. For example,

-What is the normal reference data? (The kinematic data vary greatly according to gait speed)

-Should the several gait cycles be averaged or not?

-If several cycles should be averaged for the interpretation, How many gait cycles should be averaged to analyze of patients' gait?

-The position of passive marker on skin surface can not be put on exactly same site before and after the certain treatment in spite of every efforts.

-Is the data from the one gait analysis system comparable to that another gait analysis system?

Because there will be many experts in gait at the meeting, I want to know the current knowledge about above several questions in the workshop. We should establish the methodology to run the gait analysis system to make an objective, reproducible data for clinical purpose and research design.

Secondly, my Lab. does not have a biomedical engineer. (The National Insurance system in my country does not reimburse the high cost of the gait analysis, so we cannot charge the appropriate price to insurance company or patients).

Thirdly, is there a specific recommendation which can not be made if the gait analysis is not performed in the management of spastic patients. The orthopedic surgeon in my institute uses the gait analysis data mainly for the evaluation of the surgical effect. He is reluctant to depend on gait analysis data in his surgical planning. In my experience, there are multi-joint problems in spastic patients which can't be evaluated exactly in observational gait analysis and the orthopedic management is the last procedure when there is no effect in spite of the various non-orthopedic procedures on the soft tissue. Thus I have tried to use phenol black or Botox injection, intrathecal baclofen. So we must develop the treatment strategy according to the data of the gait analysis (define characteristic gait patterns to make a guideline for treatment procedure like the nerve block or Botox injection, intrathecal baclofen, and surgery. (Adult cases as well as children).

Fourthly, although the gait analyses have used mainly for the spastic cerebral palsy children, I think it can be more applicable to adult spastic patients or amputee than children. In my country, the percentage of the geriatric population grows up in contrast to the lowering percentages of the children, we must apply this test to adult geriatric patients and there should be an advantage in clinical practice or research area.

Fifthly, I do not use much of the gait analysis for the evaluation of the L/E orthosis and prosthesis because there is not many cases of amputee in my country compared to the United States, and a lot of patients refuse to use orthosis. But the gait analysis can be a useful to develop or evaluate new prosthetic and orthotic designs (for example, the articulated plastic AFO, floor reaction AFO are really superior to the conventional plastic AFO).

Susan Sienko Thomas, M.A.

Gait analysis as a patient assessment tool.

Computerized gait analysis has been used for many years as a method to document both normal and pathological movement. The necessity for quantitative assessment of pathological movement is the complex three dimensional interactions between joints and the subsequent response from the muscles. Visual and clinical assessment alone make it difficult to determine the primary and secondary compensations found in pathological gait. Therefore, the use of three dimensional gait analysis provides a mechanism from which all planes of motion at several joints can be evaluated simultaneously, thus allowing closer evaluation and interpretation of the abnormal motion. In addition, gait analysis provides the documentation necessary to assess treatment outcome whether it be surgery, orthotic/prosthetic management or therapy.

The use of gait analysis as a patient assessment tool is limited by the following: the lack of link segment model standardization and marker placement between different systems and different laboratories; the lack of an accurate model which demonstrates the complex motion which occurs at the foot; the lack of consistency in the processing methods used in data analysis which may modify or change the clinical interpretation; the lack of normal age matched databases available to compare abnormal gait patterns; the lack of trained individuals to perform and interpret the gait analysis assessments; and the exorbitant cost of the gait analysis systems.

Gait analysis could be improved by the development and implementation of a standardized model which would be utilized by all motion measurement systems. The development of this model would dictate the processing techniques thus providing a basis for patient comparison and data sharing between labs. The use of a standard model would also allow for data sharing between all systems thus providing a mechanism for which norms from various labs around the country could be combined for a large variable age database.

Use of gait analysis assessments in treatment planning and/or treatment implementation. The information gained from the gait analysis can be effectively used in the determination of various treatment plans. Gait analysis can provide a quantitative assessment of the pathological gait pattern compared to normal and/or to their pre-treatment movement pattern. The use of gait analysis can determine primary and secondary gait deviations which allow for treatment options to be directed toward the primary problems.

The use of gait analysis as a tool in the treatment planning is limited by: the lack of standardization between centers in the interpretation of the data, specifically in the more complex areas of moments, and powers; recommendations from the gait analysis appear to be based more on the experience level of the physician than solely the information gained from the gait analysis; the poor understanding by clinicians of the relationship between electromyographic (EMG) patterns and the pathological gait pattern; the lack of understanding by the referring physicians and therapists of the data and subsequent recommendations resulting from the gait analysis. Although gait analysis is extremely good at providing quantitative documentation from which the results from the treatment interaction can be measured, it has not yet been proven that the recommendations that result from the use of gait analysis provide better treatment recommendations than they would have if gait analysis were not used. Gait analysis has not been shown to reduce the number of surgical interventions and subsequently the cost of treatment for individuals with movement pathology.

Gait analysis could be improved through continuing education courses at minimal cost provided to personnel involved in gait analysis to share ideas, discuss interpretation of data in an open, non-threatening format. Continuing education courses could benefit both physicians directly involved in the interpretation and physicians referring the patients, as well as all individuals including the engineers and gait lab clinicians. Greater emphasis should be placed on research aimed at determining whether the use of gait analysis influences treatment decisions, improves the quality of care and reduces the cost of treatment.

Factors which prevent the people with locomotion disabilities from accessing gait analysis.

Although the availability of gait analysis is increasing, gait analysis still remains a restricted resource for many individuals most specifically adults with pathological gait. Due to the significant amount of research on the benefit of using gait analysis with children with cerebral palsy, many of the laboratories are established at pediatric facilities under the direction of physicians who are most familiar with pediatric neuromuscular disorders. This restricted use is only one reason that access to gait analysis is limited.

Access to gait analysis still remains a major problem for the following reasons: cost of the service and subsequent reimbursement for services by the insurance companies; distance required for travel to the closest laboratory and lack of knowledge on the part of physicians and therapists that this technology is available and the benefit of the information received from an assessment.

A significant emphasis needs to be placed on educating the insurance companies about the benefits of gait analysis including the increased understanding of the pathological gait pattern which will improve treatment recommendations and possibly the cost of the overall treatment plan. Improved advertising abilities and education of referring physicians and therapists should be made available in regions which gait analysis services are readily available. A central database should be made available so that should a physician want a gait analysis for their patient, they may be able to determine the laboratory which is closest to the patient.

James C. Wall, Ph.D.

In the report of the NIH Gait Research Workshop, which was published in 1977, many issues were raised which are still pertinent today. One of these was raised by Dr. Burstein who stated that "*... right now we have almost no clinically useful diagnostic tools that can be taken outside of the heavily-financed research laboratory.*" If I am reading this comment correctly, a plea is being made for objective gait measurements that can be obtained by clinicians faced with the day to day task of assessing, treating and monitoring patients with gait abnormalities. This situation remains today with the result that the vast majority of the decisions about treatment of gait abnormalities are based on subjective assessments. For all the advances that have been made in measurement of gait and in the number of advanced, well equipped clinical gait laboratories that now exist, there has been a failure on the part of the gait analysis community to address the needs of the therapist or clinician that is daily involved in assessing, treating and monitoring patients with gait problems. This is compounded by the fact that the majority of therapists are much less interested in assessment, particularly objective measurement, than treatment, even though they will agree that treatment decisions must be made in the light of an assessment and that numerical data would certainly help. It is quite the paradox but points out that it is not simply the lack of practical objective measurement systems for them to use, but that objective gait analysis is also not perceived as a priority.

The truth is that there are simple objective measures which could be used clinically, particularly for obtaining outcome measures. For example, walking speed and stride time could be measured using a simple stopwatch and from these stride length could be calculated. So with minimum equipment the basic temporal/distance parameters could be measured. If they did nothing else they would greatly improve upon what is now being done.

I think that part of the problem in getting clinicians to use objective gait measurements is their lack of knowledge about gait, both normal and pathological, particularly with respect to the interpretation of gait data. Perhaps this is where we need to start. There then needs to be a concerted effort to provide them with tools that will aid their subjective assessment by providing objective measurements. The clinical gait analysis community should be involved in this process since they are in the best position to advise clinicians on these measurements and how and when they should be used. For example, some guidelines might be provided on the measurements that should be taken before a referral is made for a more comprehensive gait analysis. Once we know which measurements should be made and under what conditions, we should then develop clinically practical techniques for their determination.

In the light of these comments I would like to make the following recommendations:

Recommendation #1.

Develop educational materials which will promote an understanding of normal and pathological gait, with particular emphasis on interpreting the results from gait analyses.

Recommendation #2.

Develop practical objective gait measurement techniques that are valid and reliable and which can be used by clinicians involved in assessing, treating and monitoring patients with gait problems.

Kimberly A. Wesdock, P.T.

The major issues in gait analysis in rehabilitation are multi-faceted and relate to evaluation procedures, interpreting the data, using the data for research purposes, and accessing gait analysis. Different laboratories across the country use different gait analysis systems to evaluate similar patient problems in individual ways. That is, everybody is "doing their own thing" and typically billing for these services to third-party payers. All gait laboratories must be held accountable for their actions, and therefore guidelines and standards must be established. This standardization procedure has been initiated by the North American Society of Gait and Clinical Movement Analysis (NASGCMA), but this endeavor is in the early stages. Additional groundwork must be laid to assure that all issues - clinical, research, and access to care - are addressed. Specific issues of concern include:

I. Assessment

A. Standardizing ***Clinical Evaluation*** procedures, including nomenclature.

B. Standardizing ***Marker Placements*** - What is the reliability within and among laboratories?

C. Standardizing ***Equipment*** - Presently, gait laboratories are using different software and camera systems. Are these systems equally accurate and produce comparable data?

D. ***EMG*** Analysis: Fine wire vs. surface - When to use and why?

E. ***Energy Expenditure***: Oxygen Consumption vs. Mechanical Energy vs. Physiologic Cost Index - Are these measures of energy expenditure valid and reliable? How are different laboratories using this information? Can laboratories use this information in a standardized way? Which diagnoses can specifically benefit from this evaluation (in addition to cerebral palsy)?

F. ***Functional Assessments*** - Are laboratories using evaluation tools such as the Gross Motor Function Measure (GMFM) to correlate functional gross motor skills with gait? Are laboratories routinely performing motion analysis during functional activities other than gait such as stair-climbing, upper extremity reaching tasks, trunk movements, etc.? (For research or clinical use?)

II. Interpretation of the Data

A. ***Joint Powers*** - Are laboratories using this information in a standardized way when analyzing gait and making treatment recommendations?

B. ***Diagnosis-Specific Testing*** - Do gait laboratories evaluate and interpret the data differently, for specific diagnoses? What are the inherent physical and functional problems specific to each diagnosis that gait analysis can evaluate and longitudinally document? Given the natural history of progression of individual diagnoses, can gait laboratories provide useful information upon which to base treatment decisions? (e.g., cerebral palsy vs. juvenile arthritis vs. myelomeningocele vs. dystonia).

C. ***EMGs*** - Do gait laboratories interpret EMG findings in a standardized way?

D. ***Reporting the Data*** - Standardization of report formats among gait laboratories will assist in collaborative research endeavors, education and training, and third party reimbursement.

III. Clinical Recommendations

A. ***Surgical vs. Non-Surgical Recommendations*** - Many laboratories are primarily evaluating children pre- and post-op orthopaedic surgery. Other physicians who may benefit from gait analysis include: physiatrists, rheumatologists, neurologists, etc. How can gait laboratories best serve these other specialties as well as individuals with various movement disorders?

B. ***Physical Therapy Recommendations*** - Multiple physical therapy recommendations can be made after gait analysis. With collaborative research efforts, the efficacy of many treatment techniques can begin to be evaluated. However, follow-up gait analysis studies are necessary to accomplish this goal, and third party reimbursement is often difficult to obtain, as are physician referrals for repeat testing.

C. ***Bracing Decisions*** - Do gait laboratories make recommendations for orthoses in a standardized way? What patient populations would benefit from these analyses?

D. ***Follow-Up*** - Are repeat gait analyses routinely performed to document the effects of all therapeutic interventions (surgical and non-surgical) after the initial analysis? Gait laboratories need a standardized way of documenting functional outcomes, such as a national database, so that information can be used for education and research purposes.

IV. Research

A. ***Accessing Funds*** - Clinical laboratories housed in hospitals that are not university-affiliated (and do not have Ph.D. personnel on staff) often wish to participate in research efforts. These gait laboratories must be made aware of available research funding for specific projects.

B. ***Research Design and Priorities*** - What are the pertinent research questions to answer? How can laboratories design studies to best utilize staff time and effort? How can individual laboratories initiate and/or coordinate multi-center collaborative studies? Which diagnoses should be targeted?

C. ***Statistical Analysis*** - Workshops at national gait conferences are imperative in assisting new researchers in the field to statistically analyze gait data.

D. ***Outcomes Database*** - The establishment of a national diagnosis-specific database will assist all laboratories in documenting the natural progression of different disorders as well as functional outcomes. Additionally, this information will be necessary for third-party payers to justify services.

V. Accessing Gait Analysis

A. ***Barriers*** - preventing access to gait analysis include demographics, prohibitive cost, lack of knowledge by potential referring sources, and questionable benefits. These barriers must be investigated and prioritized, and action plans implemented to reduce or eliminate the barriers.

B. ***Age Discrimination*** - Many gait laboratories (including some "centers of excellence") are located within childrens' hospitals which often do not serve individuals over the age of 21. This issue must be addressed to improve access to gait analysis centers for all individuals with movement disorders, regardless of age.

C. ***Funding*** - should be allocated to ensure that all U.S. consumers have equal access to gait analysis, regardless of demographics and ability to pay. For example, a plan should be established for individuals in the Midwest states (many of which do not have laboratories) to access gait analysis. Even if insurance companies or non-profit organizations agree to pay for testing, how can assistance be obtained for families to travel out-of-state to existing laboratories, and who assists with lodging and miscellaneous costs?

Recommendations Needed for Advancement in Gait Analysis

1. Standardization of nomenclature, methodology, equipment, interpretation, and reporting used in gait analysis.

2. The establishment of diagnosis-related guidelines for evaluation and testing.

3. The establishment of a national database to document the longitudinal progression of different diagnoses before and after therapeutic intervention.

4. Collaboration among different laboratories to initiate multi-center studies investigating clinical questions and documenting functional outcomes.