Journal of Rehabilitation Research and Development

Rehabilitation R & D Progress Reports 1990

III. Functional Assessment

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[100] C SCAT: A Method for Differential Diagnosis of Tremors Based on Their Response to Mechanical Loads _____

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Purpose—This research and development project is meant to test the idea that more definitive distinctions can be made among types of pathological tremor by observing the variation of objective tremor characteristics with applied mechanical loads. This hypothesis is based on earlier work in this group and elsewhere, in which sensitivity, or stability of frequency-domain tremor descriptions to added masses, springs, and dampers were used as the basis for investigating tremor mechanisms. C SCAT (Computer-Based System for Clinical Assessment of Tremor) is meant as a prototype instrument for use by neurologists to diagnose movement disorders in a way which will offer more reliable prediction of the effect of drugs and obviate trial-and-error prescription.

Progress/Methodology—The first C SCAT unit has been completed. It is a one-degree-of-freedom manipulandum based on a brushless dc motor digitally controlled to simulate variable amounts of added mass, damping, and elastic resistance. The entire device is mounted for clinical convenience on a cart which provides the necessary sturdy base and lockable casters. The host computer is mounted on the bottom shelf of the cart with the clinician interface monitor on top. A system of adjustable fixtures, limb cuffs, and supports makes it possible to test a patient's left or right arm in wrist extension/flexion, forearm supination/pronation, and elbow extension/flexion.

A patient being tested with C SCAT is asked to perform a simple tracking task presented by means of successive illumination of LEDs arranged in an arc immediately adjacent to his/her limb segment when it is secured in the device. The clinician conducting the test interacts with it through a friendly interface based on a keyboard and menu displays on a color monitor. An extremely detailed database management system has been built-in to facilitate collection and study of expected experimental evaluation data.

Future Plans/Implications—Experimental evaluation has begun at the Brockton/West Roxbury VA Medical Center. Clinical reactions as well as objective data will be collected. The primary task will be to determine if our hypothesis is correct that differences in tremor mechanism which determine drug response can be detected with a test protocol of practical length. The long-term goal will be to correlate tremor profiles generated with C SCAT to drug response for a large group of subjects.

Recent Publications Resulting from This Research

Design of Patient Interface and Assessment Manager for Computer-Based Tremor Characterization System. Brongo D, Masters thesis, MIT, 1990.
An Impedance Simulator for the Assessment and Diagnosis of Human Limb Tremor. Loney T, Masters thesis, MIT, 1990.

[101] Psychomotor Test to Evaluate Hand Sensory Substitution Devices: A Pilot Study

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Purpose—The purpose of this study was to develop a psychomotor test for evaluating motor performance and function of patients before and after being fitted with sensory substitution devices. A pinch force psychomotor task was constructed with associated apparatus. Test reliability and sensitivity of a psychomotor test paradigm for studying pinch force control was performed using normal subjects.

Methodology—An isometric strain gauge pinch dynamometer was designed, constructed, and interfaced to a microcomputer. The dynamometer was independent of point-of-application, permitting convenient orientation against the fingers. The rapid contract and release task required exertion against the dynamometer at or above a minimum predetermined exertion level as rapidly as possible, using the thumb and index finger. A pointer on the oscilloscope discretely jumped a fixed distance and a chime sounded simultaneously every time the required force level was achieved. The exertion was then released as quickly as possible, and the release had to be less than a predetermined lower force level. After the lower force level was reached, the pointer on the oscilloscope discretely returned to the original position, and another chime sounded. The effect of required force level, intra-subject hand differences, and test-retest were studied using a full factorial repeated measures experimental design.

The dynamometer was calibrated by suspending weights from its handle in the plane of greatest sensitivity. Software was developed for controlling the test apparatus and administering the pinch force psychomotor test. A squared Plexiglas™ box was built to cover the base of the dynamometer, and also to serve as a rest surface for the subject's hand when using the dynamometer. A strength test was administered to every subject prior to performing the psychomotor tasks for establishing appropriate force levels for each hand. A 3-minute rest period was provided between exertions for preventing fatigue. The strength test was repeated twice for each hand, and the greatest force level achieved was taken as the strength. The required force levels selected in the study were 5%, 20%, 35%, and 50% of the subject's maximal voluntary contraction (MVC). Subjects performed eight counterbalanced experiment conditions, namely, two hands by four required force levels, continuously. Performance measures included reaction time, time-to-peak force, peak force, and over-grip force.

Results/Implications—A pinch force psychomotor test has been successfully developed and constructed. We have measured performance of normal individuals to provide an indication as to whether the task proposed is sensitive to force control effects associated with the insensate hand and other sensory-motor disabilities. Preliminary studies indicated that force has an important effect on pinch rate. An experiment was performed to study the reliability of this test and to establish normal ranges. These preliminary studies indicated force requirement has an important effect on pinch rate. The average reaction rate of subjects was from 2.28 to 7.00 times/sec at 5% MVC, from 1.84 to 5.00 times/sec at 20% MVC, from 1.40 to 4.40 times/sec at 35% MVC, and from 1.20 to 3.56 times/sec at 50% MVC.

The original concept has proven feasible and a pinch force psychomotor test has been developed and tested. It is now available for quantitative testing of hand sensory substitution devices, and thus could form the basis of a project on development of a sensory substitution system for the hand. Another application of this work also became apparent during its development; it could potentially form the basis of a new project on quantitative testing of hand function in the spinal cord injured individual before and after upper extremity tendon transfers.

[102] Rehabilitation Efficacy for Brain and Spinal Injury

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Sponsor: *Centers for Disease Control*

Purpose—The main objective of this project is to determine the reliability, validity, and scaling properties of the Functional Independence Measure (FIM), and the Modified Barthel Index (MBI), two functional assessment measures that have broad utility and general acceptance in rehabilitation medicine.

Progress/Methodology—Each of 10 hospitals are collecting type and duration of therapies received by 15 traumatic brain injury (TBI), and 15 spinal cord injury (SCI) patients. FIM scores and the duration of various nursing care and education activities over a 24-hour period near the beginning and toward discharge of rehabilitation are also being collected.

Implications—Establishing a valid measure of disability and handicap will better enable clinicians and researchers to plan cost-effective treatment, allow for increased effectiveness and efficiency of care, enhance prediction of rehabilitation outcomes, and to examine the relationship between burden of care imposed on nursing staff and FIM scores.

[103] Portable Microprocessor-Based Heart Rate Processor

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Sponsor: *Hugh MacMillan Rehabilitation Centre*

Purpose—This project is an exploratory study into the possibility of using heart rate as an objective indicator of arousal states (especially states of excitement and enthusiasm, or lack of such states) in severely multiply disabled children. The goals of this study are the application and evaluation of a newly developed portable heart rate monitor and data processing algorithm, and the exploration of heart rate data as an indicator of the effect of sensory stimulation interventions with children who are nonspeaking and severely motorically impaired.

Methodology—A portable unit that measures and stores the interval between ventricular contractions (R-to-R interval) was developed. Data collected by the "beat box" can be downloaded to a MS/DOS-compatible computer.

A total of 30 minutes worth of data can be collected before downloading.

A prototype of the device is currently being field-tested with students of the Hugh MacMillan Centre School. Three children from the Sensory Stimulation class will be invited to participate.

The procedure will be as follows: 1) 5 minutes of rest in low illumination condition; 2) 5 minutes of rhythmic music; 3) 5 minutes of rest in low illumination condition; 4) 5 minutes of toy activation; 5) 5 minutes of rest in low illumination condition; and, 6) 5 minutes of rhythmic music and full illumination.

It is hypothesized that the heart rate for the activity periods will be noticeably different (higher) than that for the rest periods.

[104] Determination of Ankle Range of Motion Using OMNITRACK

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Sponsor: *Hugh MacMillan Rehabilitation Centre*

Purpose—The objective of this pilot study is to develop a system that automatically records ankle position while the foot is moved through its range by the clinician.

Patients being fitted with ankle-foot orthoses (AFOs) are required to have a range of motion about the ankle such that they can be placed in a neutral position. Those with contractures, for instance, may be impossible to place in a neutral position, and are therefore unsuitable candidates for AFOs. Presently, the clinician physically manipulates the foot and ankle and makes a subjective opinion about bracing.

Methodology—OMNITRACK is a device that was developed in the Electronics Programme for the quantification of posture. The hardware consists of a 3-degree-of-freedom potentiometer-based position sensor and a data acquisition card for the IBM-PC. With this hardware, the position of the end of the sensor, with respect to the sensor's base, can be calculated in three dimensions. The hardware was enhanced with the addition of a platform on the end of the sensor. The platform was attached through three additional potentiometers, giving the sensor a total of 6-degrees-of-freedom. With this addi-

tion, it becomes possible to use OMNITRACK to measure the position and orientation of the platform with respect to the sensor base.

Analysis of the system is very similar to the forward kinematics problem in robotic arms. A frame of reference is assigned to each potentiometer, and the Denavit-Hartenberg convention is used to define the relationships between frames. It then becomes possible to determine the position and orientation of the frame of reference of the platform with respect to the base.

The shank is held upright with Velcro™ straps attached to a fixed frame. The platform is placed on the bottom of the foot. The clinician moves the foot through its range of motion and the platform moves with it. By calculating the orientation of the platform, it is possible to determine plantarflexion/dorsiflexion, inversion/eversion and internal/external rotation at each instant.

Results/Implications—The system is able to automatically record ankle range of motion. Further design work is required to minimize the effect of twisting of the bones of the foot relative to the ankle joint, which reduces precision of the inversion-eversion measure of the ankle.

[105] ELITE: A Fully Automatic 3-D System for Movement Assessment

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Purpose—The purpose of the ELITE project is the development of a fully automatic, unobtrusive movement analyzer to be used for routine work in clinical evaluation, diagnosis, therapy and prostheses assessment, and for research applications in neurology and orthopedics.

Methodology—*System overview.* The system is based on optoelectronic noncontact means (TV cameras), and is divided into two levels of intelligence devoted to image-processing, and high-level data processing.

First level. The first level processes in real-time the images taken by two or more CCD/TV cameras leading

to the two-dimensional (2-D) coordinates of small light-weight passive markers placed on the subject's anatomical landmarks. Because a special shape recognition algorithm is used for their detection, high resolution is attained by using small markers. The algorithm is based on a hardware-implemented, real-time bidimensional cross-correlation between the incoming TV image, and a reference kernel which gives high correlation values only for marker-shaped objects. The computation of the center of mass of the cross-correlation values on all the pixels belonging to one marker leads to an increase in the 2-D resolution to 1/65000 of the field.

Second level. The second level is implemented on an AT/IBM-compatible computer (80286/386/486 microprocessors). It provides for distortion corrections, matching between markers, coordinates, body landmarks, three-dimensional (3-D) coordinates, reconstruction, and other further processing. Matching with the body landmarks is a problem that always arises when passive, noncoded markers are used. It has been solved by combining a dynamic tracking procedure with a knowledge-based model of the movement under analysis. This approach has led to a fast, automatic algorithm suitable for routine applications. The 3-D coordinates of the markers are computed by an iterative least-squares algorithm based on the linearization of the colinearity equations. Further processing includes the data filtering and derivatives assessment. This problem has also been solved with a new technique using AR signal modeling. The procedure is fully automatic and very fast. Other processing includes force platform data analysis, body modeling, and graphic representations.

System performances. The system can work with very small markers with respect to the field of view (FOV) (plastic hemispheres of 0.8 cm of diameter on a 3 m FOV), and is very flexible with respect to the calibration volume. Analyses on lip movement involving a 30cm-sided cube have been done, as well as full body double-sided analyses with 5 meters of FOV; obviously the marker dimensions and lenses vary accordingly. The use of reflective paper coating markers, of stroboscopic solid-state infrared lighting, of TV cameras electronically shuttered (1 ms), and of the shape recognition hardware

allows the operation of the system in any environment, even outdoors, allowing for maximum freedom in the experimental set-up. The 3-D calibration of the working volume is easily performed in less than 5 minutes by using a control object carrying a grid of markers. The accuracy obtained on the 3-D coordinates is one part on 3,000 of the FOV, and is sufficient for the major part of the analyses related to the rehabilitation field, considering the high sampling rate (100 Hz). The derivative assessment algorithm has shown a very good accuracy on the third derivative also and, compared with other techniques, has given similar or better results, but with a dramatically lower time consumption and without requiring any *a priori* information on the processed signal.

Recent Publications Resulting from This Research

Automatic Analysis of Lips and Jaw Kinematics in VCV Sequences. Magno Caldognetto E et al., in Proceedings of Eurospeech 89, J.P. Tubach, J.J Mariani (Eds.), 453-456, 1989.

Hierarchical Approach to 3D Movement Analysis. Ferrigno G, SPIE Proceedings, 1356:2-7, 1990.

Pattern Recognition in 3-D Human Motion Analysis. Ferrigno G, Borghese NA, Pedotti A, ISPRS J Photogram Remote Sensing, 45:227-246, 1990.

A Technique for the Evaluation of Derivatives from Noisy Biomechanical Data by a Model-Based Bandwidth-Selection Procedure. D'Amico M, Ferrigno G, Med Biol Eng Comput 28:407-415, 1990.

An Algorithm for 3D Automatic Movement Analysis by Means of Standard TV Cameras. Borghese NA, Ferrigno G, IEEE Trans Biomed Eng (in press).

Comparing Differentiating Procedures for Kinematic Data. D'Amico M, Ferrigno G, Proceedings of VIII Isek, Baltimore (in press).

[106] AUSCAN System: An Optoelectronic Analyzer of Posture

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Purpose—The purpose of this research concerns the development and clinical application of a new automatic system, named AUSCAN, for nonionizing three-dimensional (3-D) measurement and analysis of kinematic and dynamic variables associated with human posture.

Methodology—The AUSCAN system is a new automatic TV-based analyzer of the 3-D variables of posture. Depending on the type of postural test to be carried out, a number of small reflective hemispheres are placed on the patient's body to mark the most proper anatomical

repair points. For example, when studying scoliosis in orthostatic or dynamic conditions (i.e., during bending or stepping), the markers are located on: zygomatic bones, mentum, acromions, sterno-clavicular joints, apophysis of sternum, anterior superior iliac spines, posterior superior iliac spines, knee joints, heels, and spinous processes from C7 down to S3 every second vertebra. After that, the patient is asked to stand on a suitable forceplate which allows, during the whole test, the reconstruction of the spatial-temporal evolution of the ground reaction force. At the same time, two pairs of

CCD cameras work simultaneously to pick up both the front and back view of the patient on the forceplate. Both the video and the forceplate signals join into the hardware kernel of the AUSCAN system where they are preprocessed. The video signals, after suitable conditioning, are sequentially sent to a specially developed architecture (FPSR) for parallel computation. The FPSR is fed with a video image every 10 ms, thus scanning the four cameras in 40 ms. The FPRS main roles are the recognition, inside the original images generated by the cameras, of only the markers placed on the subject, and the computation of their coordinates. The algorithm which the FPSR uses for recognition of markers is a hardware implemented bidimensional cross-correlation function. The particular architecture of the FPSR allows the recognition of any number of passive (reflective) markers present in every single image from any complex environment. A personal computer (where the obtained numerical data has been entered), performs the final data processing, storage, and representation of the results. The AUSCAN system's basic accuracy, originally of just one part over 256 the field of view, is now largely improved by employing a special software algorithm for the estimation of the true center of each marker in space. Such an algorithm leads to an experimentally proved final accuracy of better than 1/3500 the field of view (i.e., an accuracy much better than 1 mm in case of using a field of view more than adequate for total body analysis).

Results—The primary application of this system has been the analysis of curvatures and rotations of the rachis in normals and scoliotic patients. Preliminary results have pointed out interesting information about the variability of data in normal subjects and, moreover, the effects induced on the patients' spinal deformity by different therapies (e.g., electrical stimulation, braces, surgical intervention, etc.).

Future Plans—The use of the AUSCAN system will continue by following the scoliotic patients' recovery, and by also taking into account further cases in the area of neurological disorders.

Recent Publications Resulting from This Research

The AUSCAN System in the Analysis of Posture. Sibilla P, Pedotti A, Santambrogio GC, in Proceedings of the IRMA 90, Madrid, Spain (in press).

Frequency Content of Bending Test Kinematics: A Study to Determine the Optimal Data Filtering. D'Amico M, Ferrigno G, Santambrogio GC, in Surface Topography and Spinal Deformity VI (in press).

Three Dimensional Analysis of Posture. Pedotti A, Santambrogio GC, Sacerdoti CG, in Proceedings of the XVIIth Meeting on Vertigo, Nausea, Tinnitus and Hypoacusia Due to Head and Neck Trauma, Bad Kissingen, West Germany (in press).

[107] Rating Scale Analysis of Functional Assessment Measures

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Purpose/Methodology—The main objective of this project is to determine the reliability, validity, and scaling properties of the Functional Independence Measure (FIM), and the Modified Barthel Index (MBI), two functional assessment measures that have broad utility and general acceptance in rehabilitation medicine.

Rasch Analysis will be used to examine these properties in 13 impairment groups from data collected by the Uniform Data System for Medical Rehabilitation. The need for adequate measurement of disability is apparent both in patient care and clinical research for determining compensation, predicting prognosis, planning placement, estimating care requirements, choosing types of specific care, and indicating changes in status.

The objectives of this study are to: 1) assess the utility of Rasch analyses in scaling the FIM and MBI as measures of burden of care, or severity of disability; and, 2) examine change of functional status from admission to discharge, and discharge to follow-up, with scaled scores from the FIM and MBI.

[108] Spherical Coordinate Virtual Environment for Limb-Loading Experiments

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Sponsor: *National Institute on Disability and Rehabilitation Research; Burke Rehabilitation Center*

Purpose—This system was built as an experimental facility for conducting experiments on human motor control; in particular, for research on disabling tremor. It is essentially a 2-degree-of-freedom spherical coordinate robot controlled via digitally-supervised analog loops to behave as a virtual environment. In addition to combinations of inertia, damping, and elasticity, it can simulate detents, rigid walls, and other physical elements. It can also introduce force perturbations. It is based on two brush-type DC servomotors driven by pulse-width-modulated amplifiers. Direct coupling between the device handle and the motor shafts is accomplished by a unique gimbal linkage. For tremor research, the system permits limb-loading as a system identification technique, that is, as a means of modeling tremorogenic mechanisms from their response to changes in apparent limb impedance.

Progress—The system has been subjected to extensive tests to fully characterize it. The efficacy of the redundant safety mechanisms has been confirmed. Early experimental trials have demonstrated the ability to alter a subject's tremor in frequency and amplitude by elastic loading.

Future Plans/Implications—A protocol has been designed to apply the manipulandum to study of "tremor coordination" (i.e., the relationship between tremors in different degrees of freedom of the same limb). This scheme will involve successive splinting of different degrees of freedom of subjects' arms to separate the contributions of individual joints, followed by collection of data on unsplinted movement.

Recent Publications Resulting from This Research

A High Performance Two Degree-of Freedom Kinesthetic Interface. Adelstein B, Engineering Foundation Conference, Santa Barbara, 1990.

[109] Development of Improved Seating Assessment Review Procedures

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Sponsor: *Scottish Home and Health Department, Chief Scientist's Office*

Purpose—This is a preliminary project intended to develop methods and equipment for quantifying the effects of sitting postures. These are to be incorporated into routine assessment and review procedures for seating. The feasibility of using these procedures is to be determined on a preliminary basis.

Methodology—The following seating characteristics are to be quantified as described below: 1) muscle tone: monitored by EMG instrumentation already developed at this Centre; 2) joint angle: flexible goniometers will measure joint angles; 3) interface pressure: monitored by pressure transducers using either electropneumatic or electrohydraulic techniques; and, 4) spinal shape: measured indirectly by Oxford Metrics ISIS system.

The above measurements are to be made on a sample of seating patients seen at the Centre, and the results incorporated into the routine patient assessment procedures on the basis of a feasibility trial.

Progress—Funding has been approved for this project which commenced in November 1990.

Future Plans—Depending upon the outcome of this feasibility study, an extended series of trials using these techniques will be conducted to monitor the long-term effects of seating provision.

[110] Objective Functional Assessment and Rehabilitation of Low Back Disability

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Sponsor: *Scottish Home and Health Department; The Mactaggart Trust*

Purpose—Our purpose is: 1) to develop and analyze a model of low back disability which relates physical deconditioning to psychological distress and illness behavior; and, 2) to test that model in the clinical reconditioning and rehabilitation of British patients with low back disability.

Progress/Methodology—The main objective of the first half of this project was to test and standardize the Cybex Isokinetic Back Assessment System for the objective functional assessment of patients with low back pain. This data collection was completed within the planned 18 months. Complete isokinetic data, including torso flexion/extension, torso rotation, and lift-task has been collected on 70 normal subjects and 120 patients. Complementary clinical and psychometric assessment has been carried out on the patients. Subgroups of 20 normal subjects and 20 patients have repeated the complete isokinetic assessment on four occasions to examine test-retest reliability, inter-observer reliability, and learning effect. This data is being analyzed.

Future Plans—The final 18 months of this project will be devoted to the second objective of a controlled trial of isokinetic exercises versus non-isokinetic exercises for the treatment and rehabilitation of patients with low back pain. This is presently being planned.

[111] Programming Disorders in Fine Motor Skills: The Clinical Application of a New Assessment Procedure

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Sponsor: *Stichting Kinderpostzegels*

Purpose—The aim of the project is to implement a recently-developed procedure for the assessment of fine motor skills in a clinical rehabilitation setting. The procedure was developed at the Nijmegen Institute for Cognition Research and Information Technology (NICI) in close cooperation with the Department of Research and Development of the St. Maartenskliniek. The procedure enables clinicians to register fine motor behavior in an easy, objective, and patient-friendly way.

Methodology—Simple figures or trajectories are drawn by a patient on a digitizer using a pressure-sensitive pen connected to a computer. This set-up makes it possible to record movements (displacements of the pen) with a sample frequency of 100 Hz, and to analyze the movements in terms of the following kinematic variables: velocity, acceleration, pressure, fluency, movement time, and reaction time. The drawing as an end result is not as important as the movements leading to it, which are the focus of the procedure; that is, changing the figure or the trajectory of specific aspects (number of repetitions, complexity, and/or direction of strokes).

Implications—Research revealed that the above-mentioned kinematic variables are sensitive to changes in the motor system caused by pharmacological agents, damage, fatigue, or therapeutic intervention. Aspects of the motor system are revealed that had remained hidden in normal clinical observations.

The method offers opportunities for analyzing the motor performance of children in a clinical context because the tasks are very simple and can be repeated many times (the normal behavioral repertoire of children). The method can be used in children over 4 years of age.