THE USE OF A TRACKING TEST BATTERY IN THE

QUANTITATIVE EVALUATION OF NEUROLOGICAL FUNCTION

By Brian S. Repa

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ABSTRACT

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QUANTITATIVE EVALUATION OF NEUROLOGICAL FUNCTION

Brian Stephen Repa

In the present research, a number of tracking tasks that have proven useful to control engineers and psychologists measuring skilled performance have been evaluated for clinical use. Normal subjects as well as patients with previous diagnoses of Parkinson's disease, multiple sclerosis, and cerebral palsy were used in the evaluation. The tests that were studied included step tracking, random tracking, and critical tracking.

A position control stick with negligible dynamics and a large range of movement was employed to keep response limitations imposed by the equipment to a minimum. An over-size display screen with large vertical lines for target and follower helped to reduce the effects of any patient visual problems. The standard quantitative performance measures, reaction time and movement time, integrated absolute error, and estimated effective time delay, were used.

The tests were administered to a group of young normals, ages 18 to 21, and to a group of older normals, ages 50 to 74, to obtain quantitative standards against which patient performance could be compared and to assess the importance of age, sex, learning, and hand dominance on performance. Ten of the older normals participated in a test-retest study to determine reliability measures. Five of the six tracking indices had reliability coefficients significantly different from zero at or above the 5% level. Learning effects, measured with the same subjects, were not statistically significant.

Significant differences in performance with age were found for the step reaction time and step movement time measures. These differences were attributed to a more cautious approach taken by the older subjects. While males tended to perform better than females, statistically significant differences were observed only for the movement time measures in the young normal group and were attributed to large differences in strength. No differential effects for right versus left handed performance were noted in a sub-group of 8 young normals.

A factor analysis of the new tracking measures and selected measures from two established quantitative clinical test batteries, the CQNE (Clinical Quantitative Neurological Examination) and the SADLE (Simulated Activities of Daily Living Examination) was performed using 20 young

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normals. The analysis demonstrated that the tracking measures were comprehensive in that each of them loaded heavily on a different factor. In addition, integrated absolute error was found to measure a factor identified as Rate Control which was previously lacking in the CQNE.

As an evaluation of practical utility the tracking test battery was used in a drug trial designed to compare the efficacy of amantadine versus placebo in treating 28 parkinsonian patients already receiving optimal doses of L-DOPA. The tracking measures provided information that was useful in detecting modest but statistically significant changes in motor performance. The findings were verified by comparison with more established qualitative and quantitative measures of performance, including the professional opinion of two attending neurologists.

Phase plane diagrams of step tracking responses and power spectral density functions of random tracking error provided dramatic pictorial characterizations of the performance of patients with movement disorders. Both techniques offer a compact way of describing tracking behavior while still retaining the important features of the actual movement patterns involved. The phase plane method, in particular, appears to offer promise for objectively evaluating intention tremor.

The results of the present experiments encourage the continued use of tracking tasks as assessment procedures in a clinical environment. They have proven to be reliable, valid, and sensitive measures of neurological function.

PREFACE

This report was part of a dissertation submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Bioengineering) in the University of Michigan, 1972. The doctoral dissertation committee was: Drs. R. W. Pew & W. T. Tourtellotte, Co-Chairmen, G. V. Edmonson, R. M. Howe, W. J. Williams, and J. W. Albers.

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CHAPTER I

INTRODUCTION

Approaches to the Study of Movement Disorders

The capacity of man's motor system plays a prominent role in deter-

mining the effectiveness with which he carries out his daily activities

and responsibilities. The problems presented by patients with neuro-

logical disorders are many, and some of the most devastating are those

involving movement control. The symptoms may include involuntary

abnormalities or simply a reduction in normal movements. The evaluation

of motor disabilities has received increased attention during the last

few years with a number of approaches being used to assess the functional

capacity of patients with neurological disorders.

First, there is the skilled but subjective approach of the clinical

neurologist using the standard neurological examination. This examina-

tion includes evaluations of mental state, coordination, gait, and

equilibrium, sensation, reflexes, the motor system, and the cranial

nerves. The sum total of the patient's performance on each of these

separate categories is referred to as his neurological function. In

the standard examination, evaluation of motor capacity is based upon

the patient's subjective responses and the neurologist's qualitative

interpretation. Judgments are made by the neurologist concerning such

factors as the patient's strength and coordination and are then recorded

for the purpose of comparison with judgments from similar examinations

at other times. While the neurologist is usually able to classify a

given neurological function of the patient into broad categories such
as supernormal, normal, and abnormal (mild, moderate, or severe), he
often has difficulty in detecting small but significant changes in the
patient's condition over time. Certain aspects of patient function,
such as gait and associated movements, can be routinely measured in a
subjective manner even though they do not, at the present time, lend
themselves readily to objective measures. However, objective measures,
when available, are more precise than subjective ones and are especially
useful when small changes in performance are expected.

Batteries of sensory-motor performance tests have thus become in-
creasingly popular as a means of evaluating neurological abilities.
These tests achieve considerable objectivity by using highly restricted
responses that are readily counted or timed. For example, hand speed,
reaction time, and hand steadiness are all fairly easy to measure
objectively with the result that they are far more precise than when
measured in a subjective manner. However, most objective tests of
motor performance are concerned with the completion of a specific task
or the number of tasks completed in a given interval of time with little
concern for how the outcome is achieved. The Purdue Pegboard is typical;
and it requires that the subject pick up a series of small pegs, move
them, and then place them into a row of small holes. The number of
pegs so placed within a given period of time is measured; but the process
of picking up a peg, moving it, and placing it is not examined in detail.
Thus, while tests like the Purdue Pegboard provide quantitative measures
that are useful in detecting small changes in performance, they only
grossly define the motor act itself.

Another approach to the evaluation of motor performance makes use of activities of daily living, such as putting on a shirt, squeezing toothpaste, and using a fork. Performance is measured by recording the amount of time it takes the patient to accomplish the simulated task. Since the tasks can be performed in various ways with various types of movements and since they are dependent on a number of factors such as strength, speed, and coordination, they too provide only a gross measure of performance. However, they do specifically measure functions that are of great importance to the patient and represent the ultimate in face validity.

Other approaches have utilized motion pictures of patients performing specified tasks. Many of these approaches are just minor extensions of the standard neurological examination, however, and involve movie ratings by a panel of neurologists instead of a single examiner. The industrial engineering technique of motion time study breaks a motion sequence into basic elements such as reaching, grasping, and moving and then determines from the filmed actions the time required for each of the elements. While this approach is more analytic than using raw timed scores, it still fails to capture many of the basic features of movement disorders.

A category of sensory-motor tests that retains many of the useful features of the above approaches while avoiding most of their disadvantages is that of tracking. This type of task allows the use of a wide variety of precisely described stimulus sequences which are to be matched in some way by the subject's limb movements. The subject is

required to perform continuous movements graded along various spatial and temporal dimensions, and it is a breakdown in the spatial-temporal organization of movements that is a characteristic of many neurological disorders. The movements required in a tracking task are a compromise between highly restricted movements which make response processes difficult to study and highly unrestricted ones which result in recording and scoring difficulties. Furthermore, the standard tracking apparatus provides complete access to the stimulus and response records for both on-line and off-line analysis and quantitative as well as qualitative interpretations.

Introduction to Tracking

Basically, all tracking tasks require motor responses that bring an output signal into correspondences with an input signal. In the majority of tracking tasks, input information is displayed visually on a cathode ray tube (CRT). The output is from a system that is controlled manually by the subject through a control stick which is typically operated by the hand or arm. A general representation of a tracking system is shown in Figure 1.1. The subject is referred to as the human operator because he can be viewed as an information processing system operating on sensory inputs in order to produce an appropriate motor output. The task of the human operator is to bring the system output into agreement with an input quantity known as the system forcing function or target signal. The system output is a measure of the output of a controlled element or plant which may be described by a differential equation. Since the output of the controlled element is fed back

Forcing
Function

Output

| Display | Subject | Control Stick | Controlled Element |

PROCEDURAL VARIABLES

Instructions
Practice
Experimental Design
Order of Presentation

OPERATOR-CENTERED VARIABLES

Neurological Function
Motivation
Training
Workload
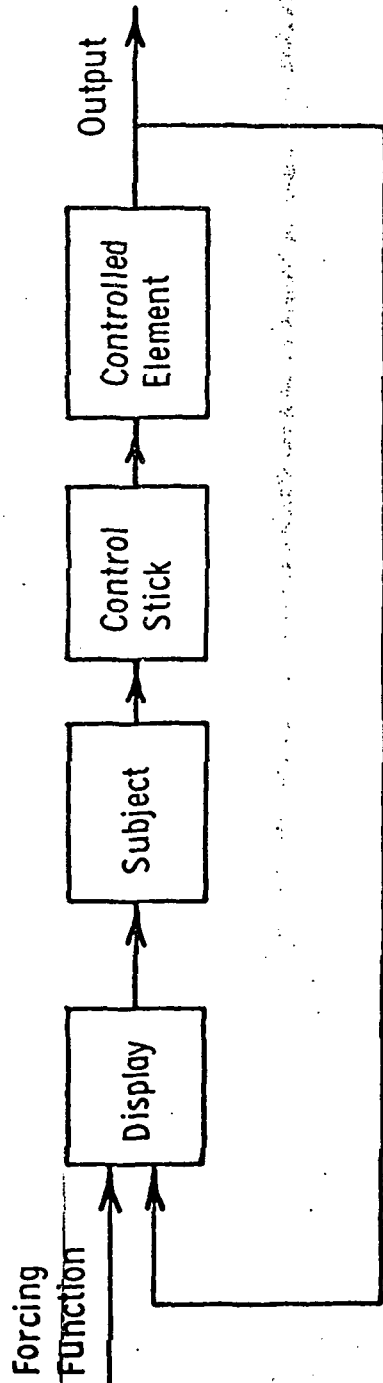
TASK VARIABLES

Forcing Function
Display
Control Stick Dynamics
Controlled Element Dynamics

Fig. 1.1 Representation of a Tracking System and the Relevant Categories of Variables.

to the input, the system is known as a closed loop control system. If the operator is presented with a display screen showing only the error between the system output and the system forcing function, the task is called compensatory tracking. If both the forcing function and the system output are displayed individually, the task is referred to as pursuit tracking. The operator controls the output of the plant by means of a control stick or manipulator which, like the plant, can also be described in terms of a differential equation. The operator thus serves as a continuous controller who perceives the system error, determines a course of action, and then communicates his decision to the system by an appropriately controlled muscular response.

Tracking research was initiated out of practical necessity, i.e., certain facts about how the human behaved as a tank turret operator and anti-aircraft gunner during World War II were required in making practical engineering design decisions. The tracking task made it possible to study rather precisely the combined sensory, decision-making, and motor behavior of a human subject as a component in a closed-loop control system. Tracking was soon applied to aircraft control and more recently to automobile and spacecraft control. As a result, an extensive and sophisticated methodology for studying tracking behavior is now in existence (two good survey papers are Summers and Ziedman, 1964 and Young and Stark, 1965).

The input and output signals as well as the general nature of the tracking task are operationally well defined and experimentally controllable. As a result, psychologists and physiologists have turned to tracking as a vehicle for studying man's basic psychomotor performance capabilities.

In fact, the potential of tracking tasks for use in clinical applications
has been recognized for many years. A number of investigators have
demonstrated the usefulness of these tasks in drug research and in
measuring the performance of patients with neurological disorders.
Stark and Iida (1961) were among the first to use tracking tasks in
studying patients with neurological disorders. Working with a group
of 20 parkinsonian patients, they performed a series of experiments
including random compensatory tracking and step tracking. Comparisons
made between normals and patients indicated that the motor performance
of the patients was severely restricted. The main interest of the
investigators was to obtain a model for predicting the important features
of parkinsonism, and their efforts were not directed to practical clinical
considerations.

Webster (1960, 1966) and others have developed control sticks which
are used to manipulate the subject's arm in order to measure muscular
rigidity. The same type of device can also be used to measure tremor
and rapid alternating movements. Webster has also used a secondary
pursuit tracking task to keep patients alert and to divert their atten-
tion while rigidity measures were being taken on their free arm; and
he found significant improvement in performance with parkinsonian patients
after drug therapy and brain surgery while standard clinical tests
showed only minimal improvement.

Johns and Draper (1964a,b) have used a step tracking device composed
of an arc-like array of neon lamps and a pointer controlled by wrist
rotation to quantify coordinated movements in both normals as well as

parkinsonian patients. They reported that the major defect of parkinsonism lay in reduced velocity of motion although reaction time was also delayed somewhat. The effect of a variety of drugs on this disorder was also reported.

Angel, et al. (1970, 1971) also tested parkinsonian patients with a step tracking task, but they purposely elicited false moves by periodically reversing the control/display polarity. Error correction times were found to be significantly longer for patients than for normals and during treatment with L-DOPA were found to be more sensitive to small changes in neurological function than either movement time or reaction time.

In a recent random tracking study by Bowen, Hoehn, and Yahr (1972), parkinsonian patients were required to track a moving target light with a photocell attached to their index finger. While this technique uses a simple time off target scoring procedure and can not be administered to patients exhibiting severe tremor, it does represent the ultimate in keeping movement restrictions imposed by the equipment to a minimum. The authors found patient performance to be significantly worse than that of a normal control group. Of more importance, however, comparison of the performance of patients with primarily unilateral symptoms with that of patients with nonlateralized symptoms suggested to the authors that the right hemisphere plays a more important role in visuospatial ability than the left hemisphere.

Eye tracking has been investigated by Melville Jones and De Jong (1971a,b) who have found that the characteristics of single saccadic eye

movements are essentially the same for parkinsonian patients and normals
except for the tendency of patients to make smaller saccades requiring
subsequent corrections. However, when rapid, alternating eye movements
between two fixed visual targets were required, it was found that the
patients took about twice as long as normal to complete a cycle of the
task. It was suggested that the impairment of oculomotor performance
appeared similar to that in the skeletal motor system of parkinsonian
patients.

Eye-tracking was also investigated in a pilot study of cerebral
palsied children by Shackel and his associates (Shackel, et al., 1962).
Grouping the data together for both saccadic and pursuit tasks, the
cerebral palsied children were found to perform 50 percent worse than
the control groups. Scoring was based on the number of saccades required
to move from one point to the next and the average number of saccadic
movements and the percentage of time off target during a pursuit task.
Another interesting finding was that eye tracking performance correlated
with age for both experimental and control groups indicating a long-term
development of eye tracking as a sensory motor skill.

Work in this laboratory (Albers, et al., 1969, 1970, 1972) has also
demonstrated the usefulness of tracking tasks in measuring neurological
function. Using constant, sinusoidal, and random input signals and
employing a force control stick, Albers showed that quantitative tracking
measures are sensitive enough to detect small individual differences in
normals as well as to meaningfully represent the performance of even the
most severely afflicted patient. Changes in patient performance resulting

from drug therapy and surgical intervention were also investigated and documented using these measures.

Objective evaluations of many of the clinical uses of tracking tasks must remain qualified, however. In general, the reliability and validity of the tests have not been reported. In the drug studies, either the number of patients used has been very small, placebos have not been administered for control purposes, or the effects of learning on improvements in performance in repeated testing have been unreported. Furthermore, only a small number of the different types of tracking tasks and tracking performance measures available have been investigated.

Criteria for Test Evaluation

The essential factors in determining the value of tracking tasks for use in clinical investigations are the reliability and validity of a representative sample of the tasks in specified clinical situations. The term reliability refers to the degree of stability or consistency with which a test will order persons on a trait continuum. Validity refers to the degree to which a test actually measures what it purports to measure. There are several operational ways of measuring both reliability and validity. No one measure is universally preferable, for the choice depends upon the way in which the test scores will be used.

The most obvious and, and in the case of sensory-motor tests, the most appropriate method for finding the reliability of a test is by means of a retest on a second occasion. The reliability is then

specified by the correlation between the two resulting sets of test scores. For tests in which two administrations cannot be considered independent samples of the same behavior the retest technique is not suitable. In this case, alternate-form reliability, where the subjects are tested with one form on the first occasion and with another, comparable form on the second, can be used. Internal-consistency reliability can also be determined by dividing the results from a single administration of a test into comparable halves and then correlating the two halves.

Numerous procedures are also available for determining validity, but they are all basically concerned with the relation between performance on the test in question and other independent information on the behavior under consideration. Four categories of validity are generally accepted; namely, content, concurrent, predictive, and construct validity. The content validity approach is commonly used in evaluating achievement tests, for it is concerned with whether or not a test or set of tests covers a representative sample of the behavior domain to be measured. It is relevant to the tracking test battery because the battery is intended to include a comprehensive sample of tracking skills. Face validity is sometimes confused with content validity. While face validity is a desirable feature of tests it is not validity in the technical sense, for it refers to what a set of tests "appears" to measure.

Concurrent validity is determined from the relationship between the test scores and other established performance measures obtained at the same time. This type of validity is especially important in evaluating

the usefulness of the tracking tests in controlled clinical trials.
The effectiveness of a set of tests in predicting some future outcome
is referred to as predictive validity. Construct validity is concerned
with the degree to which a test measures a "theoretical construct" or
trait. It is a broader, more general concept of validity that makes use
of the common implication of results from a wide variety of approaches
to get at a single "construct." Factor analysis, a statistical technique
for uncovering interrelationships between different test variables, is
of particular relevance to this concept of validity.

Selection of Tracking Tasks

The first problem in evaluating the effectiveness of tracking tasks
for use in clinical applications is the selection of a comprehensive set
of tasks. A very extensive and sophisticated methodology for studying
tracking behavior has been developed. Three task variables have a major
effect on the subject's performance--the forcing function characteristics,
the controlled element dynamics, and the control stick characteristics.
One of the keys to realizing the objectives of the present experiments
lies in the proper selection of these task variables.

Since the forcing function characteristics must be measurable and
amenable to mathematical analyses, they have typically been restricted
to step or ramp functions; sine, square, or sawtooth waveforms; a
superposition of several nonharmonic sinusoids; or a random signal
describable statistically. A wide variety of control devices has also
been used in tracking research, and the selection of such a device has

an important bearing on the strategy used by the human tracker. For
convenience, the subject's primary output can be considered as a force
applied to the control stick, in which case, the stick displacement
resulting from the force input is given by

$$J \frac{d^2 x}{dt^2} + B \frac{dx}{dt} + Kx = f(t)$$

where J is the control stick inertia, B is the damping, K is the spring
constant, x is the resulting displacement, and f(t) is the force. The
selection of a control stick can be viewed as a selection of the magnitude
of the terms J, B, and K in addition to the physical configuration, i.e.,
whether the stick is to be controlled by arm movements, wrist rotation,
finger pressure, etc. The dynamics of the controlled element can also
take a variety of forms. In general, displacement of the control stick
can be though of as producing a controlled element output given by

$$r(t) = k_1 x(t) + k_2 \int x(t)dt + k_3 \iint x(t)dtdt + k_4 \int r(t)dt + k_5 \iint r(t)dt$$

where the k_i are constants, x(t) is the control stick displacement, and
r(t) is the controlled element output. The controlled element dynamics
are thus dependent on the constants k_1 through k_5 which can be selected
with a great deal of freedom.

In addition to the variety of task configurations, there are numerous
time-domain and frequency-domain techniques available for measuring a
subject's tracking performance. In fact, almost all of the techniques
used for analyzing feedback control systems can be used to advantage in
specifying human performance. For step tracking tasks, there are time

delay, rise time, peak overshoots, and numerous other unitary measures.
For the continuous tracking situation, time on target scores and a variety
of average error scores are available. Frequency domain techniques
allow the use of still other parameters such as sensitivity, effective
time delay, and neuromuscular lag. While present data analysis techniques
do not yet allow the accurate identification of anatomical subsystems,
they do make it possible to isolate some of the functional subsystems
involved in human tracking performance.

The difficult task of selecting among the many task configurations
and performance measures presently available is simplified, somewhat,
by the existence of a number of special requirements for a clinical
application of a tracking test battery. These requirements are that
the test battery must:

(1) Include a comprehensive sample of tracking behavior.

(2) Be simple enough to be performed by patients with movement
disorders yet sensitive enough to reveal small changes in
performance.

(3) Include tests that require the shortest run lengths and
fewest trials possible.

(4) Contain performance measures that can be easily obtained
on-line.

With these requirements in mind, a tracking test battery composed
of three basic tasks was selected. So that strength and visual acuity
would not affect performance substantially a large position stick with
negligible dynamics and an over-sized display screen with large target

and follower lines were used for all the tests. Step tracking with a unity gain plant was chosen for the first basic test because it provides a somewhat simpler situation than continuous tracking for studying the timing aspects of motor responses. Since both stimuli and responses occur at discrete points in time, this type of task corresponds closely to a series of rapid positioning movements. Reaction time and movement time were selected as performance measures.

A continuous tracking task with a random appearing input signal was chosen as the second test. The random input requires the subject to depend upon the continuous observation of display error rather than his predictive abilities to make his response, thus providing data relating to the final common pathways of the neuromuscular control system. In order to keep the task as simple as possible a unity gain plant was selected. Integrated absolute error was chosen for the performance measure.

The final task included in the test battery is that of critical tracking. This task, developed by Jex and his associates (Jex, et al., 1966) is fairly easy to mechanize, does not require extensive learning, and is highly reliable, thus providing features of considerable importance for clinical applications. The task is used with no external forcing function, for the subject's own motor noise serves as an input to excite the increasingly unstable controlled element. The effective time delay, which is the single performance index of the critical task,

is a function of the subject's transport delays and central nervous

system latencies, average neuromuscular lag, and predictive ability.

Although this task has not been previously used with pathological

subjects, it has proven useful in documenting performance changes due

to small doses of d-amphetamine (Domino, et al., 1972), to long term

confinement in a space station atmosphere (Allen and Jex, 1971), and

to the stresses of heat and noise (Swisher and Maher, 1972).

The CQNE and SADLE

While tracking tasks have much to offer in quantifying neurological

function they are not intended to measure all aspects of psychomotor

performance. Investigators have long known that the total performance

capabilities of an individual cannot be specified on the basis of a

single performance test. A much more comprehensive series of tests is

required, and the most extensive battery of objective tests for evaluating

the performance of patients in controlled clinical trials is the Clinical

Quantitative Neurological Examination (CQNE), developed by Tourtellotte

and his associates. The CQNE is composed of motor and sensory tests

that purport to measure abilities that determine an individual's perfor-

mance limitations. Some of the tests included in the battery are rotary

pursuit, Purdue pegboard, visual acuity, and strength of various muscle

groups. A complete list of the test battery is provided in Chapter II.

Considerable experience has been gained with the CQNE as it has been

used in a number of studies using asymptomatic subjects to obtain

normative data and in several therapeutic trials involving multiple

sclerosis and Parkinson's disease patients. In addition, the reliability

and validity of the measures have been well documented (Tourtellotte,

et al., 1965; Kuzma, et al., 1965; Rose, et al., 1970; Potvin, 1971;

Walker, et al., 1972a,b).

A set of tests called the Simulated Activities of Daily Living

Examination (SADLE), originated by therapists in the Department of

Physical Medicine at the University of Michigan, has also been used with

the CQNE in evaluating clinical trials (Walker, et al., 1972a,b). As

its name implies, the SADLE is composed of a set of tests that simulate

simple skills of daily activity, such as putting on a shirt, dialing a

telephone, and using a fork. Test scores reflect a compound measure of

a variety of factors, such as reaction time, coordination, and strength;

and, as a result, provide little information regarding the nature of

improvement in a clinical trial. The SADLE is of importance to both

the patient and the physician, however, because it measures the patient's

ability to carry out his functional activities and, consequently, has

greater face validity than the CQNE.

Considerable research has gone into establishing the effectiveness

of the CQNE and SADLE for use in evaluating controlled clinical trials.

As a result, both batteries provide excellent standards for comparison

with the tracking test battery, which appears to fall somewhere in

between the CQNE and SADLE with regard to complexity and relevance to

functional activities. The CQNE and SADLE were administered concurrently

to all subjects and patients studied with the tracking test battery, and
they thus provided excellent external criteria for assessing the
effectiveness of the new tracking measures.

Objectives of the Present Experiments

The present experiments have been specifically directed toward the
evaluation of the effectiveness of the selected tracking test battery
in documenting and detecting changes in motor dysfunction. The empirical
studies to be reported thus take several forms.

(1) Establishing the reliability of the selected tracking test
measures in a clinical context.

(2) Studying asymptomatic subjects to obtain quantitative stan-
dards against which patient performance can be compared and
to assess the importance of age, sex, and learning on performance.

(3) Establishing the validity of the tracking test measures
through comparison with other standards in a controlled
clinical trial.

(4) Determining the interrelations between the tracking test
measures and other more established motor performance tests.

(5) Investigating more analytic procedures for describing
abnormal tracking performance.

Contents of the Following Chapters

Chapter I has served as an introductory chapter to present a back-
ground in the techniques that have been used in the evaluation of motor
disabilities, to describe the features of tracking tasks that make them

worthy of consideration for use in clinical evaluations, and to suggest

an approach for thoroughly evaluating the effectiveness of tracking tasks

for use in a quantitative clinical testing program.

With this background, Chapter II describes the subjects, patients,

and methods that were used in the evaluation of a tracking test battery

that was specifically designed for clinical use. A complete documentation

of the test apparatus is also included.

Chapter III describes the results of applying the tracking test

battery to normal subjects. The reliabilities of the tracking performance

measures as well as the importance of age, sex, learning, and hand

dominance on performance are considered.

The interrelations between the tracking test measures and upper

extremity tests from the CQNE and SADLE are considered in Chapter IV.

Chapter V describes the application of the tracking test battery

to a controlled therapeutic drug trial. The results of the tracking

battery are compared with those from more established tests which were

also administered during the trial.

The application of two advanced systems engineering techniques,

phase plane diagrams and power spectral density analysis, are considered

in Chapter VI.

In Chapter VII overall conclusions, a summary of contributions, and

suggestions for future work are presented.

CHAPTER II

SUBJECTS AND METHODS

This chapter will consider:

(1) The patients and subjects that were studied

(2) The tracking test battery and performance measures

(3) The technique used for administering the tests

(4) The CQNE and SADLE

(5) The data analysis techniques employed

(6) The experiments conducted

Patients and Subjects

Four groups including both patients and normal adults were studied in the present experiments. Each group will be considered individually.

Parkinsonian patients: The parkinsonian patients were participating in a drug study designed to compare the efficacy of L-DOPA and amantadine to that of L-DOPA and placebo in the treatment of Parkinson's disease.

The 28 parkinsonian-patients evaluated during the study were recruited from 42 patients participating in a previous study designed to evaluate the efficacy of amantadine alone in the treatment of Parkinson's disease (Walker, et al., 1972a). Patients having concurrent medical problems, questionable diagnoses, physical disabilities making it impossible for them to commute, or previous sterotactic surgery were not considered. The 28 patients consisted of 12 women and 16 men having an average age of 65.6 years, an average disease duration of 9.3 years, and an average disease stage of 2.9 based on the classification of

Hoehn and Yahr, 1967. A summary description of Parkinson's disease

characteristics is shown in Table 2.1. More complete descriptions can

be found in Selby, 1968 and in Hoehn and Yahr, 1967.

Multiple sclerosis patients: The 5 female patients were previously

diagnosed by the University of Michigan Neurology Staff as having

multiple sclerosis. All patients were ambulatory and had varying degrees

of upper extremity ataxia ranging from slight to moderate-severe.

Sensory deficit and motor weakness were minimal. The patients had an

average age of 30.6 years and an average disease duration of 6 years.

Table 2.1 gives a summary description of multiple sclerosis, with more

complete descriptions being found in Fog and Linneman, 1970 and

McAlpine et al., 1965.

Cerebral palsy patient: Heterogeneous groups like cerebral palsy

are usually not selected for group studies. In the present experiments,

however, illustrating the effectiveness of the tracking techniques is of

primary importance; and the 40 year old male patient with a previous

diagnosis of congenital cerebral palsy demonstrated minimal resting

tremor and mild spastic quadraplegia, characteristics that were

amenable to tracking analysis.

Young adult normal subjects: Ten right-handed male and 10 right-

handed famale undergraduates from The University of Michigan served as

paid subjects in the present experiments. Responding to a newspaper

advertisement, the students were required to answer a telephone questionnaire,

designed to screen out subjects with evident physical or neurological

abnormalities. In addition, all subjects passed an abbreviated

TABLE 2.1

A SUMMARY DESCRIPTION OF MULTIPLE SCLEROSIS AND PARKINSON''S DISEASE CHARACTERISTICS

Descriptor	Multiple Sclerosis	Parkinson's Disease
Symptons and Physical Signs	Euphoria, scotoma, nystagmus, paresis, slowness, spasms, intention tremor, dysproprioception, and disorders of gait, equilibrium, speech, and bladder	Easily confused, masking, bradykinesia, resting tremor, rigidity, cogwheeling, hypokinesia, and disorders of gait, equilibrium, and speech
Cause	Unknown – may be viral or auto-immune	Unknown
Lesions	Degeneration of myelin on nerve fibers scattered throughout the central nervous system	Decrease of dopamine, and degeneration of cells and myelin in the basal ganglia
Disease Onset	15 – 30 years old	35 – 60 years old
Disease Course	Varied and unpredictable with relapses and remissions and/or chronic disease progression	Slow disease progression
Life Expectancy	Almost normal	Normal
Treatments	Drugs (ACTH), surgical intervention, e.g., thalamotomy for relief of intention tremor, and physical therapy	Drugs (L-DOPA, Amantadine, anti-cholinergics, antihistamines), surgical intervention, e.g., thalamotomy for relief of resting remor, and physical therapy

neurologoical examination immediately prior to performing in the experiments. The students ranged in age from 18 to 21 years.

Older adult normal subjects: Fifteen subjects age-matched to the parkinsonian patients were also studied. Requirements for selection were that the subjects be neurologically and physically normal and right-handed. The subjects were predominantly the husbands and wives of the patients and consisted of 9 women and 6 men with an average age of 62.3 years. Ten of the subjects were re-evaluated 3 weeks after their initial testing. They consisted of 5 men and 5 women with an average age of 63.8 years.

Description of Tracking Test Battery

A schematic diagram of the general tracking task, including a summary description of the different tests used is shown in Figure 2.1. A picture of the display screen and control stick is shown in Figure 2.2. The display was positioned 80 cm from the subject. Two large vertical lines of 13 cm and 6 cm were used for the target and follower, respectively, to help reduce the effects of any patient visual problems. A large position stick with negligible dynamics was used for the control stick to keep response limitations imposed by the equipment to a minimum (see Herzog , 1967). Three types of tracking tasks were used in the test battery:

(1) Step tracking: In this task the subject was required to execute a quick adjustive movement that transferred his upper limb from one position to another. A pursuit display was used with the target line occupying one of two positions, 14 cm to the right or left of center.

FORCING FUNCTION → DISPLAY → SUBJECT → POSITION STICK → CONTROLLED ELEMENT → OUTPUT
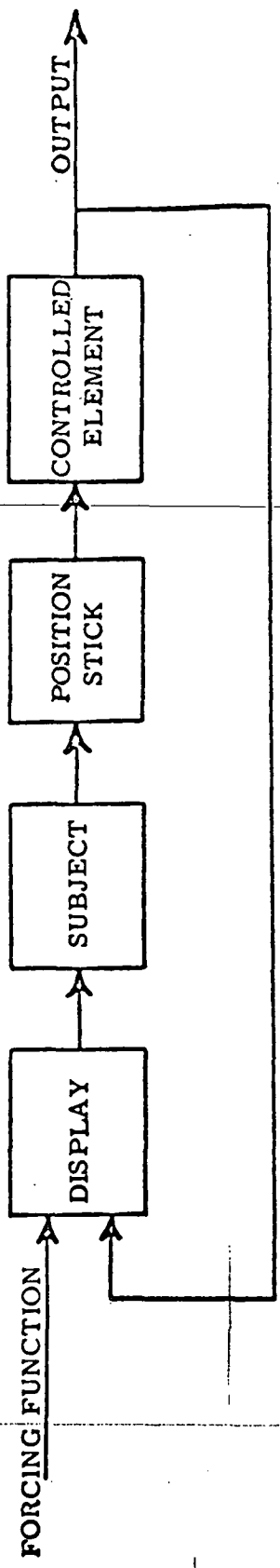
TYPE OF TRACKING	FORCING FUNCTION	DISPLAY	CONTROLLED ELEMENT	PERFORMANCE MEASURES
Step	Rectangular pulse with alternating ± 14 centimeter amplitude and pulse width from 2.7 to 5.7 seconds.	Pursuit	K	Reaction Time Movement Time
Random	Random noise with cutoff frequency of 0.3 rad/sec.	Compensatory	K	Integral of Absolute Error
Critical	None	Compensatory	$\frac{K}{S-\lambda}$; $\lambda_0 = 1.0$ rad/sec $\dot{\lambda} = .05$ rad/sec	Reciprocal of Critical Root

Fig. 2.1. General Tracking Diagram and Task Descriptions.

Fig. 2.2. Tracking Apparatus Utilizing Large Position Stick and Over-Sized Display Screen.

The task of the subject was to maintain alignment of the target and
follower. A sequence of five interstep intervals selected at random
and ranging from 3.5 to 6.0 seconds was used repeatedly with control
stick movements of $\pm20°$ required for alignment. Mean reaction time
and movement time measures for right to left and left to right tran-
sitions were calculated for the last 20 of 30 steps.

(2) Random tracking: In this task using a compensatory display,
the subject was required to follow a random appearing input signal.
The difference between the subject's output and the desired output was
displayed. The random input had a 0.3 radian/second cutoff frequency,
meaning that frequency components above 0.3 radian/second were attenuated
with the degree of attenuation increasing with frequency. A more de-
tailed consideration of how the signal was generated is shown in
Appendix C.

Five trials, each 75 seconds in length, were used, the score for
each trial being the integral of the subject's absolute position error
during the middle 45 second portion of the run. The average score for
the five trials, expressed in mm-seconds/second, was used as the test
measure.

(3) Critical tracking (Jex, et al., 1966, 1967): In this task
the subject was required to stabilize an increasingly unstable plant up
to the point of loss of control. The dynamics of the plant were
simulated on an analog computer with the plant output given by

$$r(t) = \int \lambda(t)r(t)dt + K \int x(t)dt$$

where $\lambda(t)$ increases linearly with time, K is a constant, x(t) is the control stick displacement, and r(t) is the plant output. An analogous physical task is balancing a broomstick that is getting shorter all the time. λ was initially set at a low value of 1.0 rad/second and then slowly increased at a rate of 0.05 rad/sec until the error went off scale. At this time, the computer went into the hold mode and the value of λ at which control was lost was recorded. This value is called the critical root. The score, determined by the reciprocal of the critical root and given in millisec, is an estimate of the subject's effective time delay in reponding to the continuous error signal. The average of the last 15 out of 20 trials was used as the test measure. Detailed computer mechanizations for the three tasks are shown in Appendix C.

Administration of Tracking Test Battery

To reduce variability between subjects, all subjects were read identical instructions and orientation (see Appendix B). Practical examples were used to introduce the task requirements wherever possible and fairly exact descriptions of the performance measures used for evaluation were also included.

The CQNE and SADLE

Lists of the test items in the CQNE and SADLE that were administered to the subjects and patients studied with the tracking test battery are shown in Tables 2.2 and 2.3, respectively. Cases where abbreviated versions of the CQNE and SADLE were administered will be noted in the

TABLE 2.3

THE SIMULATED ACTIVITIES OF DAILY LIVING EXAMINATION (SADLE)

Putting on a shirt
Opening a door
Managing visible buttons (three different tests)
Zipping a garment
Putting on gloves
Scrubbing a hand
Dialing a telephone
Tying a bow
Manipulating safety pins
Picking up coins
Threading a needle
Unwrapping a Band-Aid
Tearing an envelope
Squeezing toothpaste
Cutting with a knife
Using a fork
Pouring water
Drinking with a straw

TABLE 2.2

The Clinical Quantitative Neurological Examination (CQNE) Test Items

I. Vision: Visual Acuity
II. Upper Extremities
  A. Strength of Movements
    1. Grip
    2. Wrist dorsiflexion
    3. Shoulder abduction
  B. Control of Movements
    1. Steadiness
      a. Hole steadiness, supported and unsupported
      b. Force steadiness, supported and unsupported
      c. Finger tremor, resting and sustension
    2. Simple reaction time
    3. Speed of hand
    4. Speed-coordination of hand
    5. Rotary pursuit
    6. Finger dexterity
      a. Purdue Pegboard
      b. Pencil rotation
  C. Fatigue of Movements
    1. Grip strength
    2. Speed of hand
    3. Speed-coordination of hand
  D. Sensation
    1. Touch, hand
    2. Vibration sense, index finger
    3. Position sense
    4. Two-point discrimination

chapters to follow. A brief description of the test items is given in
Appendix A. The order of administration of the test batteries was
randomized from subject to subject, but tests within each battery were
always presented in a fixed order to minimize undesirable interactions
between tests.

Data Reducation and Analysis

Tracking records for the step tracking task and random tracking
task were recorded on magnetic tape and then reduced off-line. For the
step tracking task, tape-recorded signals of output velocity and target
position were displayed on paper by means of a strip-chart recorder.
Reaction time and movement time were read directly from the strip chart
record as shown in Figure 2.3. The reaction time for a given response
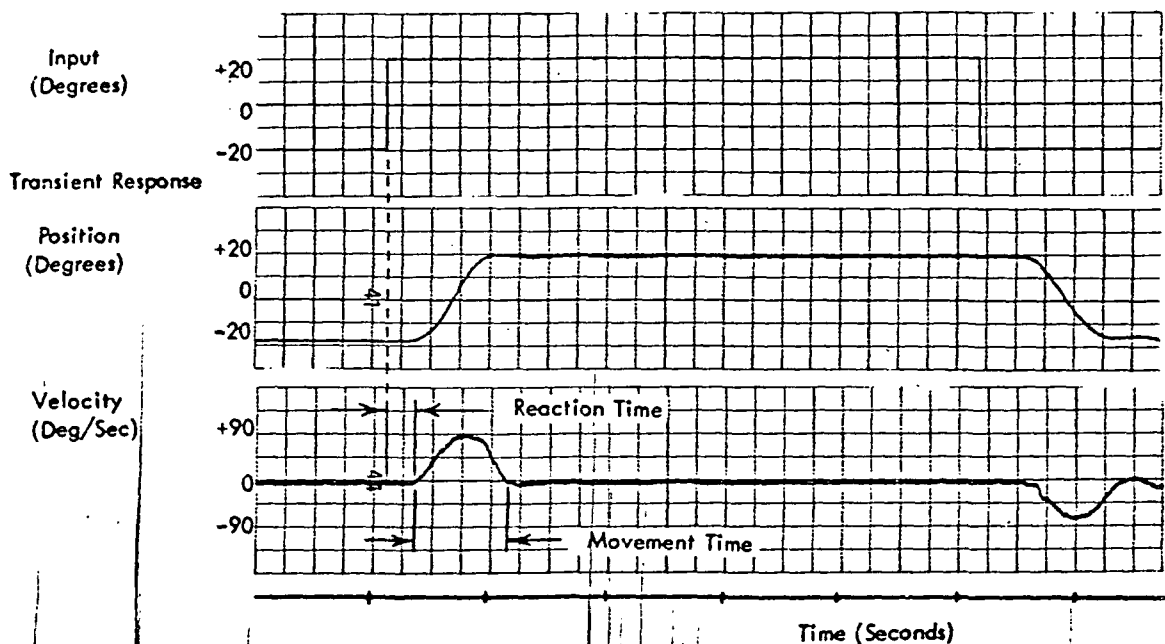
Fig. 2.3   DEFINITION OF PERFORMANCE MEASURES FOR STEP TRACKING TASK

was taken as the time between target motion and the beginning of a

deflection away from zero on the velocity curve. The ending of the

movement was defined by the point at which the velocity curve crossed

the zero level. Movement time was thus defined as the time between the

beginning and the end of the movement as determined from the velocity

curve.

Phase plane diagrams were obtained by playing back at one-quarter

real time the taped signals of output position and velocity and dis-

playing them on an x-y plotter.

For the random tracking task, the taped error signal was played

back through an absolute value circuit and then an integrator to

obtain integrated-absolute-error (IAE) scores. A timing device was

used to provide integration over the middle 45 sec portion of the 75 sec

runs. Error power spectra were obtained by sampling the recorded error

signal at 20 hz with a Hewlett Packard 2115 Digital Computer and then

computing autocorrelations which were then properly integrated by a fast

Fourier transform program to yield the power density spectra. The power

spectra were displayed on a line printer. See Appendix D for more details.

The quantitative tracking indices were analyzed statistically on

an IBM 360/67 computer using programs described in Potvin, 1971.

Description of Experiments

The present experiments have been designed to determine whether or

not tracking behavior reflects important neurological functions which

can be effectively documented in a quantitative clinical testing program.

The primary purpose of the individual experiment is denoted by the title.

Experiment 1 - Reliability: Experiment 1 was designed to examine the reliability of the tracking test measures in a context similar to that used in controlled clinical trials. Ten older adult normal subjects were tested and then retested approximately 3 weeks later to determine which of the test measures were reliable.

Experiment 2 - Effects of age: The tracking performance of 20 young adult normal subjects, 18-21 years of age, and 15 older adult normals, 50-74 years of age were analyzed to determine effects due to age. Since performance tends to decline with increasing age, it is important to choose a well matched control group when making comparisons between patient performance and normal performance. Potvin (1971) found that for the CQNE and SADLE tests "young adult normal subjects do not perform significantly better than normal subjects in the age range of multiple sclerosis (MS) patients; however, young adult normal subjects perform significantly better than normal subjects in the age range of Parkinson's disease (PD) patients..." In the present study, the older normal group was specifically age-matched to the parkinsonian patients for this reason. The performance of the MS patients, however, was compared with that of the young adult normal controls.

Experiment 3 - Effects of sex: For each of the two normal subject groups, the data were analyzed with male and female subjects considered seprately to determine the effects of sex on performance.

Experiment 4 - Effects of learning: The scores obtained on the two different occasions, 3 weeks apart, for the 10 older normal subjects taking part in the reliability experiment were used to determine the

effects of learning. In addition, trial by trial scores for both the

young normals and older normals were investigated to evaluate the

effects of short-term learning on performance.

Experiment 5 - Effects of lateral dominance: Eight young adult

normal subjects were tested on both right and left sides to determine

the effects of lateral dominance on tracking performance. Since, with

the exception of this experiment, only dominant side tracking performance

was measured for all subject and patient groups, it was felt important

to take at least a cursory look at these effects.

Experiment 6 - Interrelations between the tracking test battery

and the CQNE and SADLE: Twenty young adult normal subjects were studied

with the tracking test battery, CQNE, and SADLE on the same occasion.

The data collected were analyzed by means of factor analysis to evaluate

the interrelationships between the 3 batteries of tests. If the tracking

tests correlate too highly with already existing tests, without adding

any advantages, then they may merely represent needless duplication.

Experiment 7 - Establishing consensual validity: The tracking test

battery was applied in a drug trial designed to compare the efficacy of

L-DOPA and amantadine to that of L-DOPA and placebo in the treatment of

28 patients with Parkinson's disease. Batteries of subjective and

objective measures, including the CQNE and SADLE, were also administered.

The procedure for the study was as follows. Over a 4 to 5 month period,

the 28 patients received a gradually increasing dose of L-DOPA until

each patient reached a stable, maximally tolerable dose (see (Walker,

et al., 1972b). At this time, the patients were randomly divided into

two treatment groups. One group was given 100 mg of amantadine twice daily and the other group received a placebo capsule of identical taste and appearance twice daily. Both groups continued to receive their maximally tolerable L-DOPA dose. Three weeks later patients were evaluated and the amantadine and placebo groups were reversed. After another three week period, the patients returned for a final evaluation. The results of the tracking test measures were then compared with patients' impression, neurologists' subjective interpretations, and CQNE and SADLE results to determine their consensual validity.

Experiment 8 - Phase plane and power spectral analyses: Experiment 8 is a demonstration experiment intended to illustrate the value of 2 systems engineering methods, phase plane diagrams and power density spectra, for use in describing movement disorders. Selected tracking samples from each of the patient and normal groups were analyzed using these techniques, and comparisons were made between the graphical results and the neurologists' previous diagnoses of patient function. Step tracking performance was analyzed using phase plane diagrams and random tracking performance was analyzed using error power spectra.

CHAPTER III

NORMATIVE DATA

Whenever new quantitative tests for measuring neurological disorders
are developed, it is of interest to examine the performance of normal
subjects as well as patients on the tests. The tracking test battery
was thus administered to two groups of normal subjects:

(1) 20 young adult normal subjects, 18-21 years old.

(2) 15 older adult normal subjects, 50-75 years old, 10 of whom
were retested after 3 weeks.

The normal subjects were studied for the following reasons:

(1) To determine the reliability of the tracking task measures.

(2) To assess the importance of age, sex, learning, and
dominant versus nondominant body sides on tracking performance.

(3) To obtain quantitative standards against which patient
performance could be compared.

Reliability

The reliability of the tracking tasks was determined in a test-
retest study involving 10 older adult normal subjects who were re-
evaluated 3 weeks after their initial evaluation. Test reliabilities
are more effectively measured using normal subjects because of large
variations in the patients' performance which can be justifiably
attributed to changes in their disease state. The test reliabilities
using both Pearson product moment correlation coefficients and

34

Spearman-Brown slit-half correlation coefficients are shown in Table 3.1.
All coefficients are significantly different from 0 at or above the
5% level with the exception of the right to left movement time measure.
With the given sample size, the smallest correlation significant at
the 5% level is .63, so the movement time correlation is only slightly
below this value.

TABLE 3.1

Reliability of Tracking Test Battery Involving 10 Matched
Normals with a Three Week Interval Between the First and
Second Examinations

TEST	r[†]	$\frac{2r}{1 + |r|}$[††]
STEP TRACKING		
Reaction Time, Right to Left	.75*	.86
Reaction Time, Left to Right	.82**	.90
Movement Time, Right to Left	.60	.75
Movement Time, Left to Right	.67*	.80
RANDOM TRACKING		
Integral of Absolute Error	.91***	.95
CRITICAL TRACKING		
Reciprocal of Critical Root	.96***	.98

† Pearson product moment correlation coefficient
††Spearman-Brown split-half correlation formula
*p ≤ .05   **p ≤ .01   ***p ≤ .001

Reliabilities of test measures in the CQNE have recently been determined by Potvin (1971) using 18 young normal adults and a one month inter-test interval. Examination of those tests that purport to measure upper extremity coordination reveals that their reliabilities range from .52 to .84. The tracking tests measures, with a range of .60 to .96, thus compare favorably with the more established measures, although exact comparisons cannot be made because of differences in experimental design. Typically, the tracking measures represent a larger number of samples of behavior of each subject than the CQNE tests. While Kelly states that "The most common basis for low reliability of a set of test scores is that they are based on too few samples of behavior," Anastasi (1966) warns that "The change in nature of many motor tests with practice complicates the determination of reliability." Thus, increasing the number of test samples will not always result in increases in reliability since different test samples may not measure quite the same function.

The fact that the CQNE measures were determined with a young subject population and a larger number of subjects than the tracking measures would tend to produce higher reliabilities for the CQNE tests. One of the major generalizations in the field of aging is that older adults are prone to be more variable in their performance than younger adults (Botwinick and Thompson, 1968). Also, smaller numbers of subjects tend to affect reliabilities adversely. On the other hand, the tracking study utilized a shorter inter-test interval than the CQNE experiment which has a favorable effect on the tracking reliability measures.

In any event, the reliabilities of the tracking measures are quite good with the reliability of the Critical Task unusually high for a motor performance test.

Effects of Age

Average tracking performances for the young adult normal and older adult normal subject groups are shown in Table 3.2. In general, the young normals performed better on the tracking tasks than the older normals, which is to be expected as "one of the most pronounced changes associated with aging is the slowing of sensorimotor activities" (Tolin and Simon, 1968). Reaction time scores are significantly faster for the

TABLE 3.2

COMPARISON OF TRACKING PERFORMANCE OF YOUNG

ADULT NORMAL SUBJECTS AND OLDER ADULT NORMAL SUBJECTS

Test	Units	Young Adult Normals		Older Adult Normals		% Change	t *
		Mean	SD	Mean	SD		
STEP TRACKING							
Reaction Time, Right to Left	Milliseconds	232.3	32.1	302.8	38.9	23.3	5.86 ***
Reaction Time, Left to Right	Milliseconds	243.3	32.4	294.2	33.4	17.3	4.54 ***
Movement Time, Right to Left	Milliseconds	289.0	61.0	489.0	110.0	40.9	6.86 ***
Movement Time, Left to Right	Milliseconds	302.0	61.0	568.0	118.0	46.7	8.67 ***
RANDOM TRACKING							
Integral of Absolute Error	Centimeter-Seconds / Second	2.01	0.54	1.89	0.58	6.3	0.63
CRITICAL TRACKING							
Reciprocal of Critical Root	Milliseconds	336.9	47.3	361.7	64.3	6.9	1.32

*** = $p < .001$

*"t" is a statistical parameter which combines the size of the difference in means, the number of observations made, and the amount of random variability in the measurements. It can be evaluated by consulting the appropriate probability tables to determine the significance of the observed difference.

young normals, a finding in agreement with other investigators who have

noted that the time taken by mental processes to initiate movements in-

creases with age (e.g., Singleton, 1954 and Leonard, 1953). The large

differences in movement time scores for the 2 groups are especially

striking. The instructions for the task were to "move as quickly and

accurately as possible." A rapid movement required a high degree of

control, however, since the position stick dynamics were negligible.

It appears as if the older subjects have shifted toward increased

accuracy. Welford (1958) has suggested that such a shift might be due

to the greater care older people take in the activities in order to

avoid injury. Singleton (1955) found that with longer movements that

must be accurately aimed, speed limitations with age are set by the

perceptual and translatory processes involved in the visual guidance.

Thus, two factors, increased caution and a reduced information processing

capacity, appear to account for the slower step tracking responses of

the older group.

Both the random tracking task and the Critical Task force the pace

of performance more than step tracking. Instead of allowing several

seconds to prepare for the next stimulus and response, these tasks

require continuously graded responses. As a result, these tasks might

be expected to force the older subjects to give up their overly cautious

approach and thus raise their performance to more nearly the same level

as the younger subjects. This appears to be the case. In fact, the

older normals showed superior performance on the random tracking task,

although this may be only a technical difference. In order to make
the task within the capabilities of severely handicapped patients,
however, the bandwidth of the target signal was kept very low (0.3 rad/
sec). It is reasonable to assume that the amount of information, in
the technical sense, to be dealt with in this task was thus well within
the older normals' capacity to deal with in time. When the view that
as people get older they tend to become more accurate (Welford, 1958)
is also considered, it is not at all unreasonable to see slightly better
random tracking performance with the older group.

The same arguments cannot be made with regard to the Critical Task,
however. While the fast-paced nature of the task might cause an abandon-
ment of excessive caution in the older normal group, the lower informa-
tion processing capacity of this group would be expected to result in a
definite sacrifice in accuracy as higher and higher degrees of instability
are to be dealt with. The fact that the young normals performed better
than the older normals is thus an expected finding.

Another possible reason why the older normals performed slightly
better than the younger normals on the random tracking task may be due
to motivation. The random tracking task is quite tedious and requires
sustained concentration and subject cooperation. Older normal subjects
are usually highly motivated because of their close relationship to the
patients. The young normal subjects are paid volunteers; and even
though they are urged to perform at their best, they do not always appear
as motivated as the older subjects. Potvin (1971) compared performance
in the CQNE for incentive groups who were offered monetary rewards with

that for control groups who were given standard instructions to perform
at their best. Although no significant differences in overall performance
between these two groups were found for either young normal subjects or
older normal subjects, the young incentive subgroup showed the largest
improvements. The tests in Potvin's study were of much shorter duration
than the present tracking tasks, so motivation might be a bigger factor
in the present results.

Effects of Sex

The data for the two groups of subjects were also analyzed with
male and female subjects considered separately. The results for the
young normal group are shown in Table 3.3. While the males showed
superior performance on all of the tests, only the movement time scores

TABLE 3.3

COMPARISON OF TRACKING PERFORMANCE OF MALES
AND FEMALES FOR YOUNG ADULT NORMAL SUBJECT GROUP

Test	Units	Male		Female		% Change	t
		Mean	SD	Mean	SD		
STEP TRACKING							
Reaction Time, Right to Left	Milliseconds	227.0	34.5	237.7	30.5	4.5	0.74
Reaction Time, Left to Right	Milliseconds	237.4	30.2	249.2	35.1	4.7	0.81
Movement Time, Right to Left	Milliseconds	256.0	48.0	322.0	56.0	20.5	2.82 *
Movement Time, Left to Right	Milliseconds	268.0	57.0	337.0	45.0	20.6	3.04 **
RANDOM TRACKING							
Integral of Absolute Error	Centimeter-Seconds / Second	2.2	0.66	1.82	0.31	17.1	1.64
CRITICAL TRACKING							
Reciprocal of Critical Root	Milliseconds	323.9	35.1	349.9	55.8	7.4	1.25

* = p < .05
** = p < .01

were significantly better. Males are decidedly stronger than females.
It is fair to assume that a subject's strength will indicate the power
that he can put into causing a movement to be made rapidly. The
significantly faster movement times observed for the males are thus
to be expected.

Similar trends exist for the older normals, as shown in Table 3.4.
The differences in performance due to sex appear to decrease with age,
however.

Learning Effects

The same group of 10 older normals used in the reliability study
was also used to measure long term learning effects, as shown in Table 3.5.
Although all test scores showed an improvement on the second examination,
none of the improvements were statistically significant. The greatest
improvements occurred for the movement time measures. One of the
reasons offered for the big difference in scores between the older
normals and the young normals was the excessive caution of the older
subjects. A second exposure to the step tracking task would thus be
expected to relieve some of its unnaturalness resulting in a reduction
in their overly cautious behavior.

Improvement in performance with repeated trials for each of the
measures is shown in Figures 3.1 through 3.4 for both the young and
older normal groups. The pattern in improvement was not uniform as
some subjects showed continued improvement during the trials.

TABLE 3.4

COMPARISON OF TRACKING PERFORMANCE OF MALES
AND FEMALES FOR OLDER ADULT NORMAL SUBJECT GROUP

Test	Units	Male		Female		% Change	t
		Mean	SD	Mean	SD		
STEP TRACKING							
Reaction Time, Right to Left	Milliseconds	299.0	33.2	305.3	44.1	2.1	0.30
Reaction Time, Left to Right	Milliseconds	280.2	27.6	303.6	35.1	8.4	1.37
Movement Time, Right to Left	Milliseconds	429.0	99.0	529.0	103.0	23.2	1.86
Movement Time, Left to Right	Milliseconds	532.0	135.0	591.0	106.0	11.0	0.95
RANDOM TRACKING							
Integral-of-Absolute-Error	Centimeter-Seconds / Second	17.4	6.3	19.9	5.6	14.4	0.80
CRITICAL TRACKING							
Reciprocal of Critical Root	Milliseconds	337.1	44.7	378.1	72.3	12.2	1.23

TABLE 3.5

LEARNING IN TRACKING TEST BATTERY INVOLVING 10 MATCHED NORMALS
WITH A THREE WEEK INTERVAL BETWEEN THE FIRST AND SECOND EXAMINATIONS

Test	Units	Exam I		Exam II		Difference	% Change	t-Difference
		Mean	SD	Mean	SD			
STEP TRACKING								
Reaction Time, Right to Left	Milliseconds	308	44	305	43	-3	-.3	.27
Rreaction Time, Left to Right	Milliseconds	297	37	297	51	0	-.2	.00
Movement Time, Right to Left	Milliseconds	510	80	493	106	-17	-2.7	.62
Movement Time, Left to Right	Milliseconds	596	109	530	116	-66	-10.5	2.29
RANDOM TRACKING								
Integral of Absolute Error	Centimeter-Seconds / Second	1.93	.54	1.89	.52	-.94	-1.4	.68
CRITICAL TRACKING								
Reciprocal of Critical Root	Milliseconds	371	56	361	61	-10	-2.6	1.77
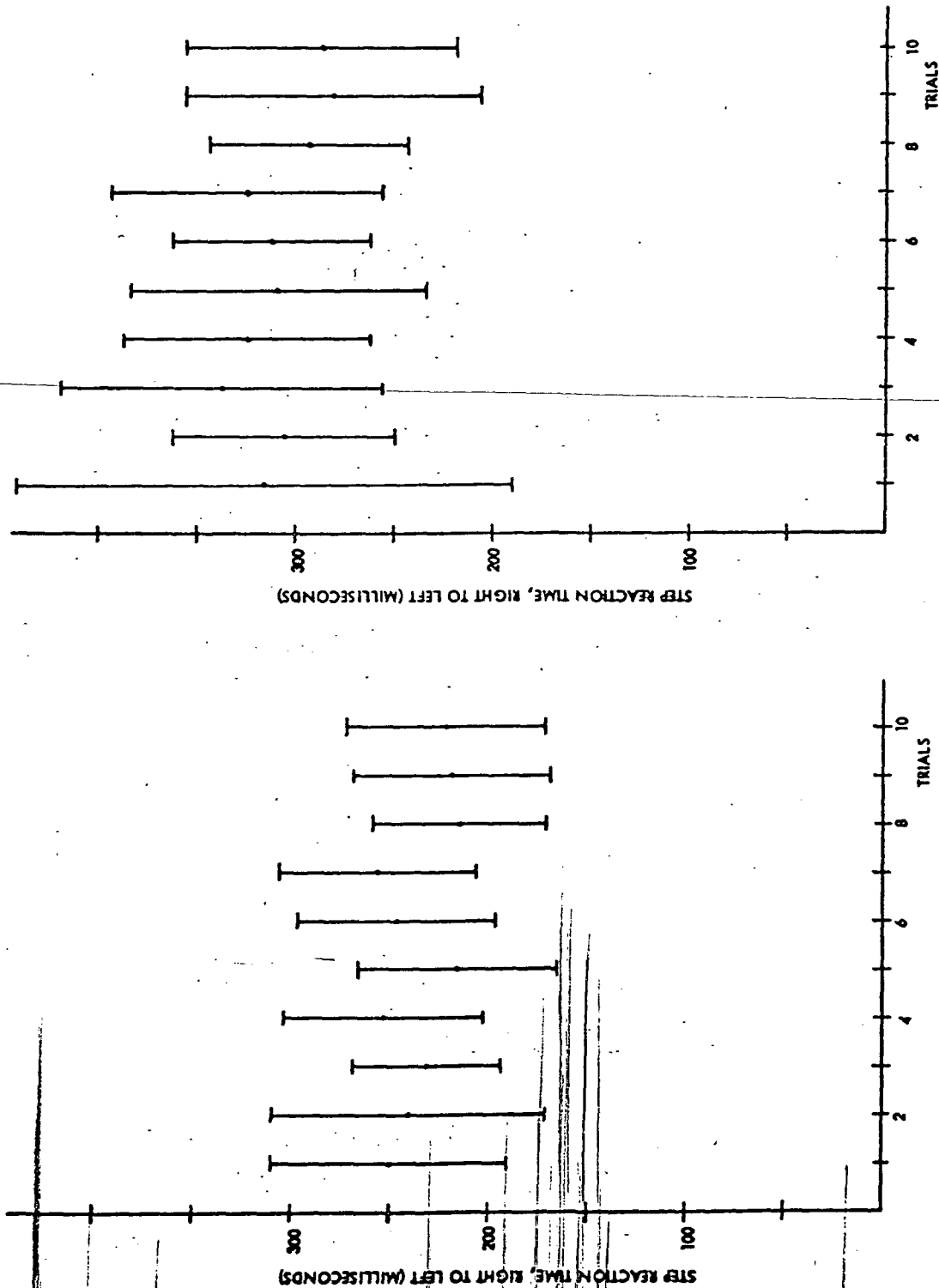
Fig. 3.1. Pooled Data from (a) 20 Young Normals and (b) 15 Older Normals Showing Means and Standard Deviations for Step Reaction Time, Right to Left with Repeated Trials.
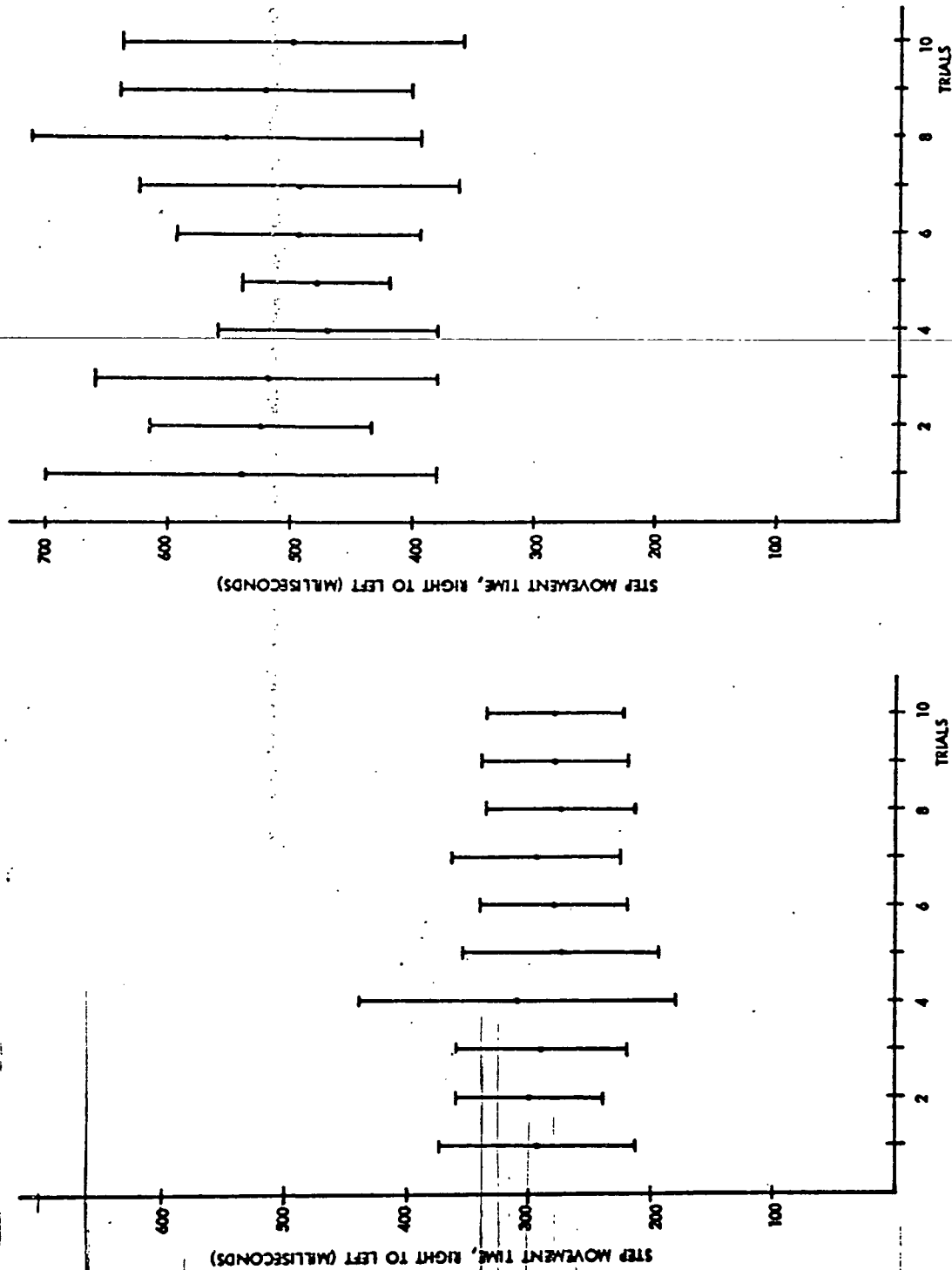
Fig. 3.2. Pooled Data from (a) 20 Young Normals and (b) 15 Older Normals Showing Means and Standard Deviations for Step Movement Time, Right to Left with Repeated Trials.
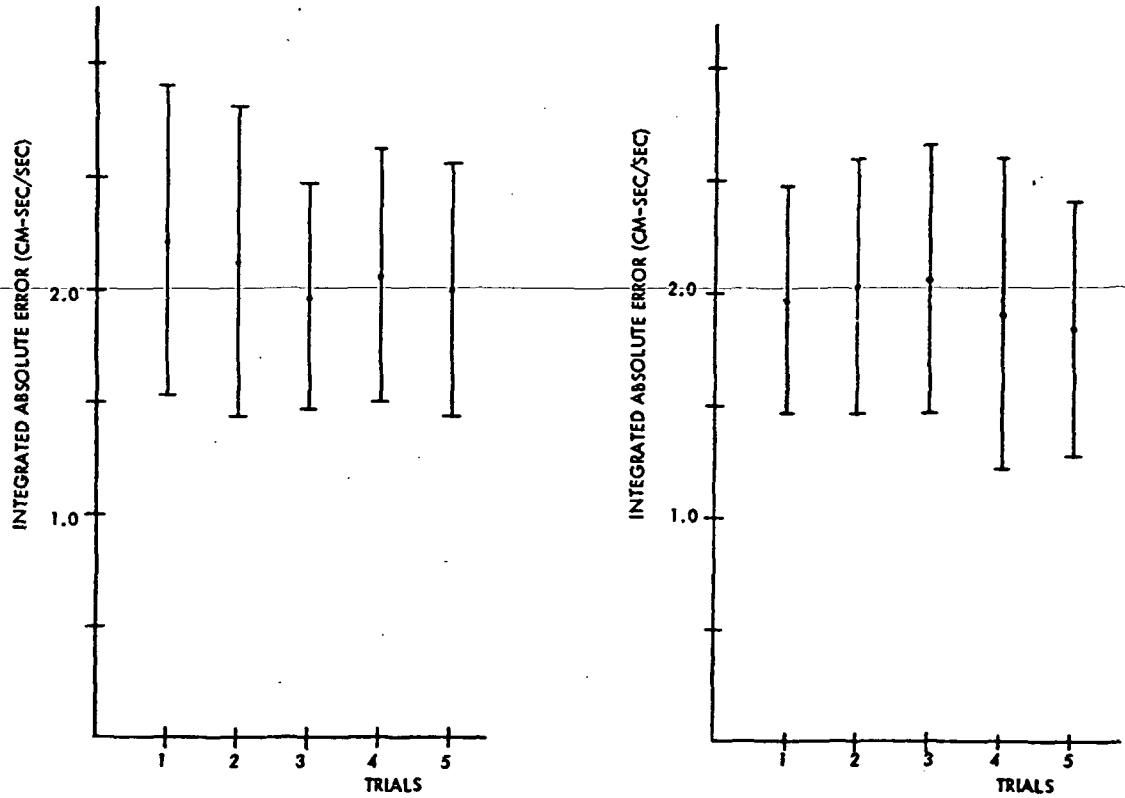
Fig. 3.3. Pooled Data from (a) 20 Young Normals and (b) 15 Older Normals Showing Means and Standard Deviations for Integrated Absolute Error with Repeated Trials.
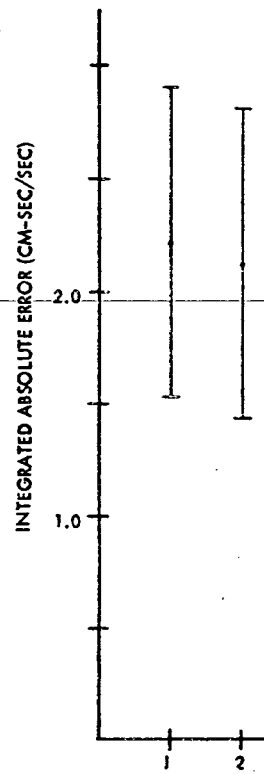
Fig. 3.3. Pooled
Normal
Absolu
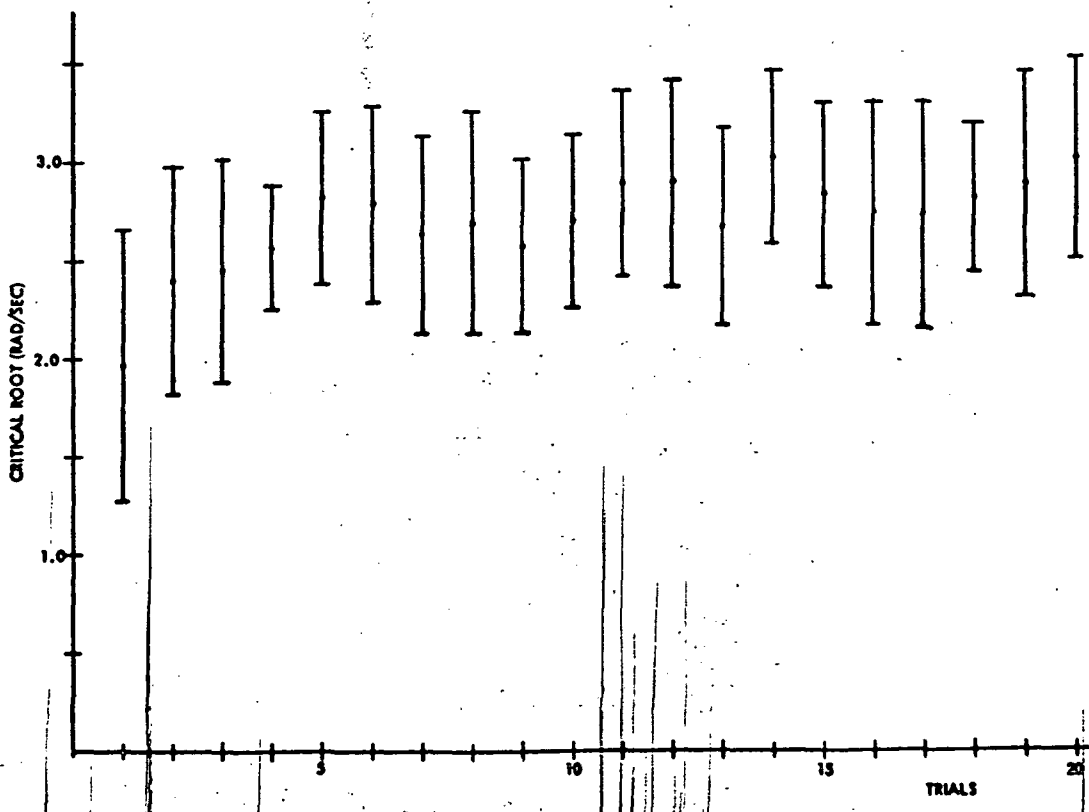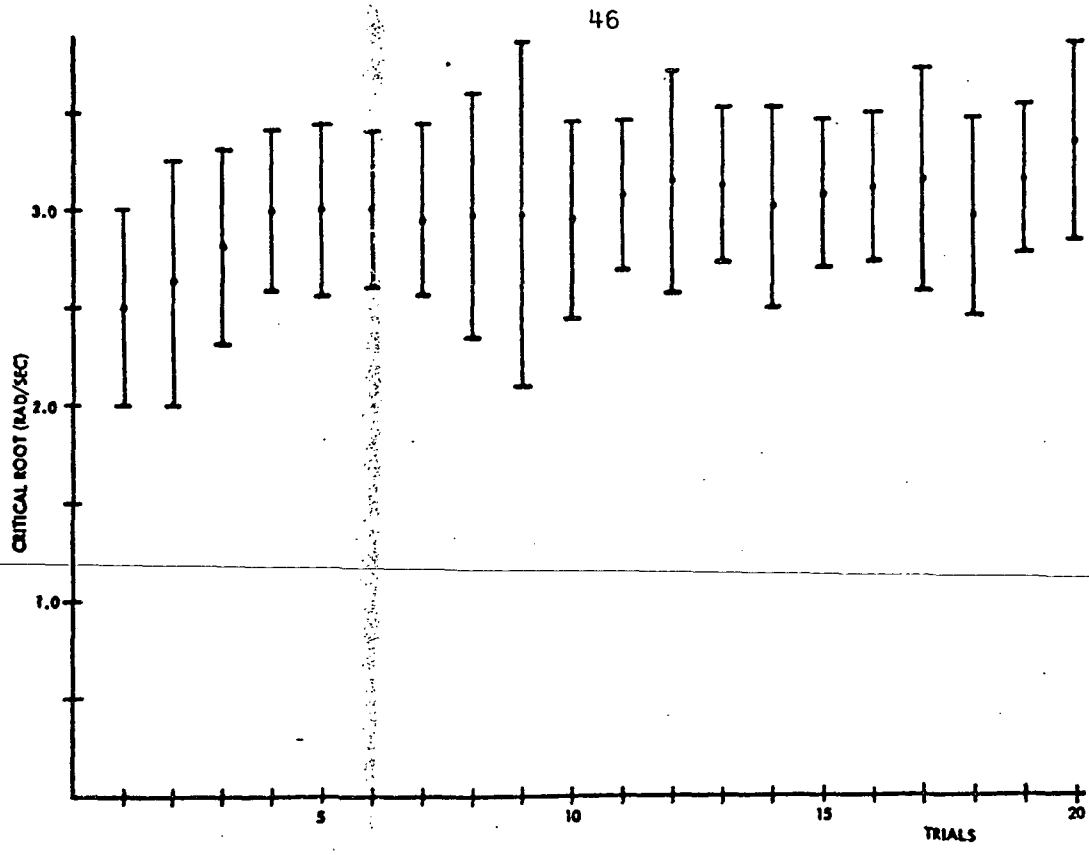
Fig. 3.4. Pooled Data from (a) 20 Young Normals and (b) 15 Older
Normals Showing Means and Standard Deviations for Critical
Root Scores with Repeated Trials.

Dominance Effects

Eight young normal subjects, 4 men and 4 women, were tested on both right and left sides to determine the effects of lateral dominance on tracking performance. Half of the subjects were tested first on the right side and then the left, while the other half were tested in the reverse order. The results of these tests are shown in Table 3.6. No significant trends are noted. While significant differences between the two body sides in activities such as throwing and handwriting would be expected, Provins (1956, 1967) claims that there should be no difference where differential training between body sides has not occurred. Bowen, Hoehn, and Yahr (1972) also failed to observe any difference in tracking performance for the two sides with their group of normal control subjects.

TABLE 3.6

TRACKING PERFORMANCE FOR A GROUP OF 8 YOUNG ADULT
NORMAL SUBJECTS COMPARING DOMINANT AND NONDOMINANT HANDS

Test	Units	Dominant		Non-Dominant		% Change	t
		Mean	SD	Mean	SD		
STEP TRACKING							
Reaction Time, Right to Left	Milliseconds	224.6	29.7	226.1	32.1	0.9	0.20
Reaction Time, Left to Right	Milliseconds	242.0	34.1	231.8	24.0	3.6	1.15
Movement Time, Right to Left	Milliseconds	285.9	53.4	291.6	53.1	3.0	0.37
Movement Time, Left to Right	Milliseconds	296.2	54.8	292.7	65.7	1.24	0.30
RANDOM TRACKING							
Integral of Absolute Error	Centimeter-Seconds / Second	2.31	0.68	2.44	0.76	6.8	0.82
CRITICAL TRACKING							
Reciprocal of Critical Root	Milliseconds	335.2	29.1	328.6	47.1	2.3	0.91

Quantitative Standards

One of the most important reasons for using normal subjects on new tests is to establish quantitative standards. Since it is the goal of the physician to bring the performance of patients to the pre-disease level, it is meaningful to express patient data as a percentage of that obtained from matched normal controls. This was done for the L-DOPA and amantadine drug study and will be discussed further in Chapter V. Chapter VI also utilizes matched-control performance records to dramatize the movement characteristics of different patient groups.

CHAPTER IV

FACTOR ANALYSIS OF TRACKING TEST BATTERY AND
SELECTED MEASURES FROM THE CQNE AND SADLE

This chapter considers a factor analytic study of the tracking tests
and selected measures from the CQNE and SADLE that were administered to
20 young adult normal subjects. Factor analysis is a statistical pro-
cedure that is widely used for identifying psychological traits. The
present study is thus of theoretical interest because it explores those
characteristics or traits that are common to the various test measures
and in so doing helps to provide a perspective on the new tracking test
variables.

A Brief Description of Factor Analysis

The starting point for a factor analysis is the correlation matrix
of the test variables. A correlation matrix is simply a table of the
intercorrelations among the tests. The fact that the variables
intercorrelate indicates that they share certain characteristics. A
factor is a grouping of variables that have a particular characteristic
in common. Inspection of the correlation matrix can sometimes reveal
the nature of some of the isolated factors, but a complete analytical
solution is required to determine the common factors necessary to
account for the observed correlations.

Factor analysis reduces the number of variables necessary to describe
an individual's overall performance to a relatively small number of
factors or common traits. The end product of the analysis is a factor

matrix which is a table of the loading of each of the factors in each test variable. Factor loadings represent the correlations between the test variables and the individual factors. The nature of a particular factor is determined from the characteristics of the variables with the highest loadings.

The Factor Analysis Model

The factor analysis program used in the present study was based on the method of principal components with subsequent "normal" Varimax rotation. It has been developed and thoroughly described by Henderson (1970). While it is beyond the scope of this chapter to cover the mathematical basis of this method, a brief description of the procedure will be given.

The principal components model is based on the following set of linear equations:

$$z_1 = a_{11}F_1 + a_{12}F_2 + \cdots + a_{1k}F_k + \cdots + a_{1p}F_p$$

$$z_2 = a_{21}F_1 + a_{22}F_2 + \cdots + a_{2k}F_k + \cdots + a_{2p}F_p$$

$$\vdots$$

$$z_j = a_{j1}F_1 + a_{j2}F_2 + \cdots + a_{jk}F_k + \cdots + a_{jp}F_p$$

$$\vdots$$

$$z_p = a_{p1}F_1 + a_{p2}F_2 + \cdots + a_{pk}F_k + \cdots + a_{pp}F_p$$

where $\{z_j\}$ is the set of p original test variables, $\{F_k\}$ is the set of p common factors, and $\{a_{jk}\}$ is the set of factor loadings ranging from

-1.0 to +1.0. In the initial formulation of the problem there are as many factors as original variables. The principal components method selects each factor so that it has the maximum amount of variance among all factors uncorrelated with the previously determined factors. It thus happens that only a small number of factors are usually required to adequately account for the intercorrelations among variables.

Once a solution has been determined it can be transformed to a different solution with the same adequacy of fit. The factors can be thought of as reference axes in terms of which each test variable can be plotted. The "normal" Varimax method rotates the factors or reference axes so that the small factor loadings are moved toward "0" and the large loadings toward "1". The result is a simplified, more easily interpretable factor pattern. Once the rotated factor matrix has been computed, the statistical process stops and the interpretation of the factors begins.

Previously Reported Factor Analyses

An attempt will be made to identify the factors found in the present study with those found in previously reported analyses. Some of the most extensive factorial research on motor functions has been conducted by Fleishman and his associates (Fleishman, 1967, 1960, 1956, 1954). They administered more than 200 different tests to thousands of basic Air Force trainees during the 1940's and 1950's with the goal of defining performance in terms of the minimum number of factors necessary to represent an individual's ability structure. A description of the major factors they have been able to identify is presented in Table 4.1

TABLE 4.1

A SUMMARY DESCRIPTION OF PSYCHO MOTOR-FACTORS IDENTIFIED BY FLEISHMAN

No.	Ability	Description	Applicable Test
1	Control precision	Fine, highly controlled muscular adjustments of the extremities	Pursuit rotor
2	Multilimb coordination	Coordination of the movements of a number of limbs simultaneously	Rudder control or two-hand coordination
3	Response orientation	Selection of the appropriate response to a visual discrimination reaction	Discrimination reaction time
4	Reaction time	Speed of response to a stimulus	Simple reaction time
5	Speed of arm movement	Speed of a gross discrete nonaccurate arm movement	Two-plate tapping
6	Rate control	Continuous anticipatory motor adjustments in tracking a moving target	Compensatory tracking or pursuit tracking
7	Manual dexterity	Fast, well directed arm-hand movements in manipulating large objects	Minnesota rate of manipulation
8	Finger dexterity	Fast, controlled manipulation of tiny objects involving the fingers	Purdue pegboard or O'Conner finger dexterity
9	Arm-hand steadiness	Precise arm-hand positioning movements minimizing speed and strength	Hole steadiness or track tracing
10	Wrist-finger speed	Speed of tapping a pencil in large target areas	A simple printed task
11	Eye-hand coordination	Successive placement of pencil dots in a large number of small circles	A simple printed task

Henderson (1970) and Potvin (1971) have performed factor analyses on tests in the CQNE and SADLE. Potvin's results are particularly relevant to the present study and are summarized in Table 4.2. While agreement between Fleishman's results and Potvin's results is not complete, numerous common factors can be identified, such as reaction time and control precision. Making identifications of factors across studies is not always straightforward. The factors and the loadings found in a particular study depend somewhat upon the nature of the data used in the analysis. Some of the conditions which influence the results are the types of tests and the combinations of tests used in the analysis. Also of concern are the subject population selected, the type of sampling used, and the testing situation that prevailed.

In this light, comparisons with Potvin's results should be the easiest to make since the present study was conducted under very nearly the same conditions. However, if one assumes that an individual's ability structure can be represented by a reasonably small number of basic traits and that factor analytic solutions do uncover these traits, then general cross-identifications should be possible even if experimental conditions are different. Whenever possible, the factor names introduced by Fleishman will be used in interpreting the present results.

Results of the Present Study

The correlation matrix of the original tests administered to the 20 young adults is shown in Table 4.3. This matrix supplies the basic data from which the factor analysis is initiated. Numerous sensory tests,

TABLE 4.2

A SUMMARY DESCRIPTION OF PSYCHO-MOTOR FACTORS IDENTIFIED BY POTVIN

Factor Number	Factor Name	Tests with Highest Loadings
1	Strength-steadiness	All strength and tremor tests, Force Steadiness Unsupported
2	Gait	Tandem Gait with Supports/ Without Supports
3	Control precision	All rotary pursuit tests, Putting on Gloves
4	Vibration sense of finger	Vibration Sense of Finger 1
5	Corrected distance vision	Corrected Distance Vision, Near and Distance Vision
6	Arm-hand steadiness from a supported position	Hole Steadiness Supported, Force Steadiness Supported
7	Arm-hand steadiness from an unsupported position	Hole Steadiness Unsupported, Force Steadiness Unsupported
8	Uncorrected distance vision	Uncorrected Distance Vision, Dialing a Telephone
9	Two-point discrimination	Two-Point Discrimination, Purdue Pegboard
10	Tying a bow	Tying a Bow, Resting Tremor
11	Reaction time	Simple Reaction Time
12	Hand speed, dominant body side	Hand Speed 1-D, Hand Speed 2-D, Large Peg Rotation
13	Skilled finger dexterity	Managing Three Visible Buttons, Picking up Coins, Dialing a Telephone
14	Putting on a shirt	Putting on a Shirt, Manipulating Safety Pins
15	Hand speed, nondominant body side	Hand Speed 1-N, Hand Speed 2-N
16	Threading a needle	Threading a Needle, Squeezing Toothpaste

TABLE 4.3

CORRELATION* MATRIX OF 35 TESTS FROM THE TRACKING TEST BATTERY, CONE, AND SADLE USING 20 YOUNG NORMAL ADULTS

TEST	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Effective Time Delay	1.00	0.16	0.02	0.16	0.20	0.32	0.31	0.25	0.23	-.08	0.26	0.55	-.11	0.06	-.02	0.13	-.09	-.14
2. Step Reaction Time, Right to Left	0.16	1.00	0.87	0.50	0.54	0.23	-.06	0.29	-.24	0.08	0.18	0.46	0.27	0.27	-.28	0.44	0.41	0.05
3. Step Reaction Time, Left to Right	0.02	0.87	1.00	0.43	0.52	0.44	-.14	0.34	-.33	0.08	-.09	0.27	0.26	0.42	-.01	0.38	0.48	0.06
4. Step Movement Time, Right to Left	0.16	0.50	0.43	1.00	0.54	0.26	-.20	0.32	-.33	0.11	0.37	0.35	0.26	0.29	-.05	0.13	-.17	0.38
5. Step Movement Time, Left to Right	0.28	0.50	0.52	0.54	1.00	0.39	0.18	0.35	-.44	-.49	0.44	0.35	-.04	0.31	0.04	0.22	0.13	0.16
6. Integrated Absolute Error	0.50	0.23	0.44	0.20	0.39	1.00	0.15	0.34	-.05	-.40	-.10	0.44	-.04	0.35	0.11	0.02	0.03	-.08
7. Putting on a Shirt	0.31	-.06	-.14	0.20	0.18	0.15	1.00	0.47	-.07	-.27	-.27	-.21	0.21	-.03	-.05	-.02	-.03	-.12
8. Managing Large Buttons	0.25	0.29	0.34	0.32	0.35	0.34	0.47	1.00	-.30	0.33	0.54	0.12	0.31	0.39	-.07	-.18	-.15	-.03
9. Managing Small Buttons	0.23	-.24	-.33	-.44	-.38	-.05	-.07	-.30	1.00	-.08	-.18	-.02	-.19	-.23	0.04	0.26	-.03	-.09
10. Using a Zipper	-.08	0.08	0.08	-.49	-.40	-.40	-.27	0.33	-.08	1.00	0.27	-.15	0.11	0.30	-.02	-.09	-.01	-.56
11. Tying a Bow	0.26	0.18	-.09	0.37	0.44	-.10	0.05	0.54	-.18	0.27	1.00	0.24	0.17	0.30	-.24	0.22	-.05	-.04
12. Cutting with a Knife	0.55	0.46	0.27	0.35	0.44	0.44	-.21	0.12	-.02	0.27	0.24	1.00	-.23	-.04	-.02	-.31	-.02	-.14
13. Using a Fork	-.11	0.03	0.27	0.26	-.04	-.04	0.21	0.31	-.19	0.11	0.17	-.23	1.00	0.19	0.19	0.33	-.27	0.54
14. Squeezing Toothpaste	0.06	0.27	0.42	0.35	0.31	0.35	-.03	0.39	-.23	0.11	0.30	-.04	0.30	1.00	-.19	0.33	-.07	0.09
15. Dialing a Telephone	-.04	-.43	-.01	0.05	0.04	0.11	-.05	0.07	-.04	-.04	-.30	0.04	-.02	0.19	1.00	0.05	-.01	0.04
16. Manipulating Safety Pins	0.13	0.41	0.46	0.13	0.22	0.02	-.24	-.16	0.26	0.09	0.22	0.31	0.33	-.33	0.05	1.00	-.07	0.04
17. Putting on Gloves	-.09	0.41	0.42	0.30	0.17	0.03	-.15	0.12	-.03	-.01	-.04	0.20	-.02	-.27	-.07	0.01	1.00	1.00
18. Grip Strength	-.14	0.45	0.30	0.30	0.16	0.03	-.15	0.12	-.09	-.50	-.05	0.14	-.02	-.27	-.09	0.01	1.00	1.00
19. Wrist Strength	-.33	-.23	-.05	-.28	-.64	-.32	-.16	0.09	-.09	-.36	-.17	-.62	-.14	-.31	-.17	-.36	-.05	-.06
20. Shoulder-Strength	-.37	-.05	-.20	-.50	-.56	-.24	-.11	0.18	0.33	0.37	-.10	-.62	-.05	-.22	-.13	-.34	-.15	-.08
21. Reaction Time	-.05	0.43	0.33	-.04	-.10	0.18	-.03	0.06	-.28	-.29	-.20	-.11	0.28	0.14	-.27	-.01	-.11	0.02
22. Hand Speed	-.19	-.13	-.34	-.35	-.30	-.28	-.29	-.28	-.05	-.08	-.27	0.11	-.62	-.25	-.19	-.27	-.15	-.21
23. Hand Coordination	0.04	-.23	-.05	0.14	0.09	0.09	0.04	-.10	-.17	-.23	-.14	0.17	-.77	-.14	0.09	-.06	-.47	0.10
24. Rotary Pursuit	-.01	-.23	-.27	-.29	-.41	-.47	-.37	-.26	-.09	-.07	-.38	-.37	-.33	-.12	-.16	-.38	-.07	0.21
25. Purdue Pegboard	-.30	-.61	-.27	-.33	-.29	0.01	-.10	-.40	-.06	-.19	-.25	-.17	-.55	-.33	0.09	-.52	-.24	-.03
26. Pencil Rotation	-.31	-.02	-.27	-.21	-.41	0.01	-.37	-.24	-.27	-.13	-.38	-.42	-.33	-.33	-.19	-.17	-.17	-.24
27. Grip Fatigue	-.48	-.02	0.30	0.20	0.21	0.42	0.15	0.01	0.31	-.10	-.18	-.07	0.01	0.17	0.30	-.17	0.24	0.36
28. Hand Speed Fatigue	0.18	-.13	-.18	-.03	-.03	-.13	-.12	-.23	0.00	-.06	0.09	-.32	-.55	-.19	-.08	0.07	-.05	-.20
29. Hand Coordination Fatigue	0.25	-.22	-.15	-.13	-.13	-.02	-.09	-.16	-.11	-.06	-.03	-.14	-.21	-.26	-.03	-.32	-.41	-.25
30. Finger Vibration	0.20	0.35	0.10	0.34	0.37	0.34	-.03	0.16	-.11	-.25	-.03	0.22	0.31	-.07	-.39	-.22	-.17	-.09
31. 2 Point Discrimination	0.20	0.35	0.41	0.20	0.28	0.34	-.10	0.36	-.03	0.21	0.42	0.45	-.18	0.27	-.08	0.24	0.21	-.15
32. Force Steadiness, Supported	-.36	-.29	-.01	-.15	-.60	-.31	-.37	0.28	-.10	0.21	0.25	-.37	0.14	0.19	0.41	0.00	0.13	-.18
33. Force Steadiness, Unsupported	-.23	-.44	-.03	-.47	-.47	-.03	-.39	-.15	-.00	0.33	-.04	-.34	-.29	-.03	0.23	-.33	-.03	-.30
34. Resting Tremor	0.11	0.07	-.14	-.15	-.07	-.31	0.09	-.33	0.04	0.56	0.15	0.30	-.17	0.03	-.45	0.13	-.25	0.12
35. Sustention Tremor	-.15	0.03	0.11	0.11	-.50	-.15	-.31	0.23	0.22	0.60	0.01	-.39	0.05	0.20	0.20	0.07	-.02	-.18

(Continued)

TABLE 4.3 (Cont.)

	TEST	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1.	Effective Time Delay	-.33	-.37	-.03	-.19	0.02	-.61	-.30	-.31	-.40	-.10	0.18	0.25	0.20	-.36	-.23	0.11	-.15
2.	Step Reaction Time, Right to Left	-.28	-.25	-.40	-.18	-.23	-.29	-.01	-.03	0.04	-.12	-.20	0.32	0.35	-.29	-.22	-.07	0.03
3.	Step Reaction Time, Left to Right	-.34	-.26	0.35	-.34	-.05	-.27	-.42	-.59	-.20	-.10	-.38	0.13	0.41	-.01	-.08	-.01	-.11
4.	Step Movement Time, Right to Left	-.51	-.50	-.04	-.09	0.14	-.26	-.33	-.27	0.20	0.03	-.05	0.32	0.20	-.15	.47	-.12	-.58
5.	Step Movement Time, Left to Right	-.63	-.58	-.10	-.30	0.15	-.44	-.29	-.41	0.21	0.08	-.13	0.37	0.28	-.06	-.47	-.13	-.50
6.	Integrated Absolute Error	-.32	-.28	0.16	-.28	0.09	-.47	0.01	-.42	-.25	-.11	-.02	0.17	0.32	-.01	-.09	-.31	-.15
7.	Putting on a Shirt	-.16	-.11	-.03	-.29	0.04	-.37	-.10	0.15	-.44	0.12	-.03	-.09	-.10	-.31	-.39	-.31	-.31
8.	Managing Large Buttons	0.09	0.18	-.06	-.28	-.10	-.28	-.40	-.24	0.61	-.23	-.23	-.10	-.06	0.26	0.15	-.09	0.23
9.	Managing Small Buttons	0.33	0.33	-.28	0.05	-.17	0.09	-.06	-.47	-.11	-.00	-.11	0.39	-.03	-.10	-1.00	-.33	-.22
10.	Using a Zipper	0.38	0.37	0.29	-.08	-.23	-.07	-.19	-.13	-.10	0.03	-.06	-.25	0.21	-.33	0.50	-.04	0.60
11.	Tying a Bow	-.17	-.10	-.20	-.27	0.14	-.27	-.38	-.23	0.14	0.02	-.33	-.03	0.42	0.25	-.04	-.04	0.01
12.	Cutting with a knife	-.02	-.62	-.11	0.11	0.12	-.37	-.17	-.42	-.07	-.12	-.14	0.22	0.45	-.37	-.34	0.15	-.39
13.	Using a Fork	-.14	-.05	0.28	-.62	-.11	-.33	-.55	-.33	-.01	0.55	-.41	0.31	-.18	0.14	-.29	0.36	-.05
14.	Squeezing Toothpaste	-.31	-.22	-.14	-.25	-.14	-.12	-.24	-.33	0.17	0.17	-.26	-.07	0.27	0.19	-.03	-.17	-.20
15.	Dialing a Telephone	-.17	-.13	-.27	-.19	0.09	-.16	0.09	0.19	0.39	0.08	-.03	-.39	-.08	0.41	-.23	-.03	-.20
16.	Manipulating Safety Pins	-.36	-.34	-.01	-.27	-.06	-.38	-.52	-.56	-.17	0.07	-.32	0.22	0.24	3.00	-.33	-.45	0.37
17.	Putting on Gloves	0.05	0.15	0.11	-.15	0.47	-.07	-.24	-.17	-.24	0.05	-.41	0.17	0.21	0.13	-.03	0.13	0.37
18.	Grip Strength	-.06	-.08	-.02	0.21	-.10	0.21	-.03	-.14	0.39	-.20	-.25	-.09	-.15	-.18	-.30	-.25	-.02
19.	Wrist Strength	1.00	0.95	0.26	0.27	-.25	0.51	-.02	0.27	-.17	-.01	-.04	-.04	-.10	-.09	0.55	-.12	-.18
20.	Shoulder Strength	0.95	1.00	0.24	-.17	-.17	0.43	-.03	0.16	-.09	-.06	-.17	0.03	-.09	0.24	0.53	-.09	0.42
21.	Reaction Time	0.26	0.24	1.00	-.19	-.24	-.05	-.41	-.14	-.16	0.18	-.02	-.03	0.05	-.32	0.03	-.17	-.50
22.	Hand Speed	-.27	-.17	-.19	1.00	-.19	0.57	0.38	0.32	-.35	-.00	-.39	-.04	-.07	-.26	-.46	-.02	-.12
23.	Hand Coordination	-.45	-.17	-.24	-.19	1.00	-.27	0.30	0.26	0.32	0.07	-.13	-.19	-.06	0.23	0.46	-.03	-.42
24.	Rotary Pursuit	0.51	0.43	-.05	0.57	-.27	1.00	0.34	0.28	0.45	-.00	0.13	-.07	0.08	-.02	0.46	0.12	0.10
25.	Purdue Pegboard	-.02	-.03	-.41	0.38	0.30	0.34	1.00	0.51	0.27	-.07	0.46	-.41	0.27	0.23	0.13	0.11	-.16
26.	Pencil Rotation	0.27	0.18	-.14	0.32	0.26	0.28	0.51	1.00	0.12	0.43	-.07	0.67	-.05	0.04	0.15	0.04	-.63
27.	Grip Fatigue	-.17	-.09	-.18	-.35	0.32	0.45	0.27	0.12	1.00	0.15	-.34	-.20	0.28	0.31	-.05	-.07	-.04
28.	Hand Speed Fatigue	-.01	0.03	0.02	-.00	0.07	-.00	-.07	0.43	0.15	1.00	0.24	0.17	-.21	0.03	0.25	-.10	-.27
29.	Hand Coordination Fatigue	-.04	-.17	-.03	-.39	-.13	0.13	0.46	-.07	-.34	0.24	1.00	0.05	-.21	-.23	-.28	0.11	-.11
30.	Finger Vibration	-.10	-.09	0.03	-.04	-.19	-.07	-.41	0.67	-.20	0.17	0.05	1.00	0.19	-.20	-.15	-.18	-.24
31.	2 Point Discrimination	0.09	0.03	0.18	-.07	-.07	0.08	0.27	-.05	0.28	-.21	-.19	0.19	1.00	0.13	-.29	0.11	-.31
32.	Force Steadiness, Supported	0.09	0.24	0.02	-.26	0.23	-.02	0.43	0.04	0.31	0.03	-.23	-.26	0.13	1.00	0.43	-.18	0.36
33.	Force Steadiness, Unsupported	0.55	0.53	0.03	-.46	0.46	0.46	0.13	0.15	-.05	0.25	-.28	-.28	-.29	0.43	1.00	0.01	0.61
34.	Resting Tremor	-.09	-.14	-.02	-.02	-.12	0.12	0.11	0.04	-.04	-.10	0.11	-.10	0.11	-.18	0.01	1.00	-.00
35.	Sustention Tremor	0.42	0.50	0.12	-.12	-.42	0.10	-.16	-.63	-.04	-.27	-.11	-.24	-.31	0.36	0.61	-.00	1.00

* Pearson product moment correlation coefficient, r. Values of r exceeding .44 are significantly greater than zero at the 0.05 level.

such as touch and position sense, were not included in the analysis

because they showed little or no variation between subjects.

Table 4.4 presents the factor pattern for the "normal" Varimax

rotated factors. Before rotation, 11 common factors with variances

greater than 1.0 were isolated, accounting for 89 percent of the total

variance of the original test variables. At the bottom of Table 4.4

are listed the variance of each rotated factor, the percentage of total

variance accounted for, and the cumulative percentage of total variance

accounted for. The Varimax rotation has destroyed the property of

maximum variance of successive factors that resulted from the principal

components solution, but the percentage of total variance accounted

for by the 11 factors remains the same.

The nature of the individual factors can be determined by examining

the correlations or loadings between the factors and the original test

variables. For convenience, loadings of 0.40 and higher were arbitrarily

considered as being of probable significance and are underlined in the

factor matrix. The following factor identifications were made:

Factor 1, Reaction Time: Factor 1 has its most significant loadings

(.70's and .80's) in the two step reaction time measures and the simple

reaction time measure from the CQNE. The factor thus characterizes the

speed with which a subject responds to a stimulus regardless of the

specific response required. Putting on golves and the Purdue pegboard

test have intermediate loadings on this factor. While neither of these

tests directly resembles the simple reaction time tests, both appear to

have a reaction time component.

TABLE 4.4

FACTOR ANALYSIS OF 35 TESTS ADMINISTERED TO 20 YOUNG NORMAL ADULTS
(FACTOR PATTERN OF "NORMAL" VARIMAX ROTATED FACTORS)

TEST	1	2	3	4	5	6	7	8	9	10	11	COMMUNALITY
TRACKING TEST BATTERY												
Effective Time Delay	-.0037	-.2709	0.1284	0.2623	-.7940	0.1022	-.1625	0.1413	-.0642	-.0716	0.1661	.88
Step Reaction Time, Right to Left	0.0663	-.2404	0.2120	0.0013	-.0238	-.0305	-.1750	0.1635	0.0956	0.0527	0.0575	.94
Step Reaction Time, Left to Right	0.7616	-.2347	0.2050	-.0055	0.1420	-.0037	-.1413	0.0193	-.6967	0.2147	0.3754	.95
Step Movement Time, Right to Left	0.2368	-.0974	-.2071	-.0556	0.0392	-.3383	-.3553	0.2442	-.1707	0.0357	-.0617	.95
Step Movement Time, Left to Right	2.2403	-.7453	-.0803	-.1284	-.0258	-.1551	-.3903	0.2514	-.1247	-.0791	0.1581	.92
Integrated Absolute Error	0.1038	-.2203	-.1045	0.0519	-.3526	0.0356	0.0468	0.1236	-.2240	0.0448	0.8308	.97
CQNE												
Grip Strength	0.0531	-.0080	-.0027	0.1006	0.1154	-.5590	0.0176	-.0927	0.0145	0.0277	-.0462	.97
Wrist Strength	-.0143	0.9817	-.2360	0.0033	0.0058	0.0101	0.0159	0.1772	0.0160	-.0233	-.1975	.95
Shoulder Strength	-.0114	0.5112	-.1907	-.0441	0.0981	0.0032	-.0590	0.1522	-.0181	0.1092	-.1074	.96
Reaction Time	0.2249	0.2500	-.1015	-.2630	-.0900	0.0202	0.2204	-.0922	0.1671	-.1458	0.1000	.81
Hand Speed	-.1315	0.0371	-.2461	0.0658	0.2992	-.0966	0.1992	0.1173	0.1138	-.2708	-.2758	.88
Hand Coordination	-.2767	0.4040	-.1409	0.0573	0.0029	0.0087	0.0060	0.2019	-.0079	0.8110	0.0031	.87
Rotary Pursuit	-.1540	0.3294	-.2310	0.2453	0.6626	-.1832	0.1451	0.1563	0.0635	-.1913	-.1262	.91
Purdue Pegboard	-.2977	-.0633	-.3447	0.2271	0.3197	0.0707	-.3722	-.1062	0.0714	0.0669	0.2212	.92
Pencil-Rotation	-.3475	0.1608	-.4544	-.1171	0.0344	-.1619	-.2213	-.5665	-.0893	0.3358	-.4020	.94
Grip Fatigue	-.0158	-.0653	0.0525	-.0454	0.6465	-.2543	-.1631	-.1421	-.1365	0.3368	-.0960	.74
Hand Speed Fatigue	-.1198	-.0012	0.0622	0.0503	0.1975	0.1272	0.1991	0.1856	-.3401	0.0674	-.0428	.89
Hand Coordination Fatigue	-.1300	-.1703	-.2327	0.2614	-.0568	0.3139	0.2632	-.0052	-.0760	-.0959	-.1195	.88
Finger Vibration	-.1265	-.1023	0.0021	-.1320	-.0083	0.0215	-.0404	0.5956	-.0220	-.0618	-.0357	.90
2 Point Discrimination	0.1527	-.3004	0.1475	0.3070	0.1133	0.1671	0.5136	0.0062	0.1863	0.0425	0.4152	.80
Force Steadiness, Supported	-.3395	0.0477	0.1194	-.1535	0.4086	0.2205	-.3957	-.3442	-.3083	-.2726	-.2708	.84
Force Steadiness, Unsupported	-.0603	0.0043	0.0908	-.1004	0.3190	0.3512	-.1784	-.1953	-.1176	-.2426	0.1694	.87
Resting Tremor	-.0903	-.0790	0.2002	0.1770	-.0123	-.0606	-.0583	-.1913	0.0361	-.0905	-.0638	.85
Sustention Tremor	0.1548	0.4906	0.4114	0.0047	0.0688	0.1464	0.1610	-.2788	-.1749	-.1548	0.0880	.87
SADLE												
Putting on a Shirt	-.1042	-.1042	-.3477	-.2569	-.0490	-.4449	-.1235	-.0657	0.1457	0.0497	-.0239	.74
Managing Large Buttons	0.2767	0.1558	-.2636	-.0533	-.2421	-.0506	-.7674	0.0294	-.2693	0.0112	0.2446	.94
Managing Small Buttons	-.3004	0.3915	0.4893	0.1361	-.2474	-.0308	0.2343	0.5223	-.0187	0.0622	-.0306	.95
Using a Zipper	0.2403	0.4092	0.7722	-.0307	0.0526	0.5880	-.3273	-.2930	0.0246	-.1004	-.0168	.88
Tying a Bow	-.0401	-.1073	0.1518	-.0565	-.0507	0.0415	-.9013	-.0203	0.1138	0.0076	-.1076	.91
Cutting with a Knife	0.1797	0.0401	0.2021	0.4143	-.2407	0.2201	-.0925	0.1677	0.4205	0.0097	0.0063	.92
Using a Fork	0.2426	-.0500	0.1361	-.2478	-.0471	-.0581	-.2201	0.0608	-.0935	-.1076	-.0628	.87
Squeezing Toothpaste	0.1945	-.0554	0.2931	-.1058	0.0914	-.5413	-.3667	-.1971	-.0244	-.2204	0.5258	.96
Dialing a Telephone	-.2504	-.0543	0.2445	-.0552	0.0749	-.0676	-.0802	-.3311	-.7703	-.0118	0.0731	.84
Manipulating Safety Pins	0.2051	0.1727	0.0050	-.1556	-.0375	-.0227	-.3494	0.1347	0.0592	0.0118	-.0090	.88
Putting on Gloves	0.4472	0.2692	-.0402	0.1523	0.1058	0.1499	0.0239	0.1996	-.1712	0.7234	-.0966	.93
Variance of Factor	3.6002	3.6184	4.4057	2.5014	2.8204	4.5359	3.0520	4.5935	1.9554	2.3442	1.9519	
Percent of Total Variance	10.29	14.91	7.10	8.23	6.06	6.63	8.74	7.41	5.59	6.70	5.58	
Cumulative Percentage	16.29	25.20	32.30	40.59	48.66	55.35	64.07	71.48	77.07	83.76	89.34	

Loadings having a magnitude greater than .40 are underlined.
Scores for dominant body side only (all subjects declared themselves right-handed).

Factor 2, Wrist and Shoulder Strength, Speed, and Steadiness:
Wrist strength and shoulder strength (.90 and .92) load most highly on
this factor. Other tests with high loadings (.60's and .70's) include
the step movement time measures, cutting with a knife, force steadiness
unsupported, and sustention tremor. Factor 2 thus appears to involve a
combination of strength, speed, and steadiness. Strength and speed are
positively correlated while strength and steadiness are negatively
correlated. Zipping a garment, managing three small buttons, and the
rotary pursuit task also have moderate loadings. The sign of the
loadings on the first two of these tests suggests that the test measures
are negatively correlated with strength and speed, a somewhat puzzling
relation.

Factor 3, Finger Dexterity: Factors 3 and 7 offer some difficulty
in interpretation because to a certain extent they both involve the
skillful manipulation of small objects. Manipulating safety pins (.86)
loads most highly on factor 3 with intermediate loadings (.40's) from
managing small buttons, pencil rotation, and sustention tremor. Modest
loadings from the Purdue pegboard test and putting on a shirt are also
present (.30's). In his studies, Fleishman has identified both a finger
dexterity factor and a manual dexterity factor. In an attempt to use
this classification in the present study, it was felt that factor 3 was
more appropriately identified with the former trait and factor 7 with
the latter.

Factor 4, Hand Speed and Hand Speed Fatigue: Hand speed (.69), hand
speed fatigue (.85), and using a fork (.83) have large loadings on this

factor while cutting with a knife has an intermediate loading. The fork and knife tests both appear to be highly affected by hand speed.

Factor 5, Control Precision: The loadings from the Critical Task (.79), pursuit rotor (.66), and supported force steadiness (.41) identify this factor as the ability to make "fine, highly controlled, but not overcontrolled muscular adjustments" (Fleishman, 1960). High loadings from putting on a shirt and grip strength fatigue (.60's) were also present. While the ability to make sustained muscular adjustments would be expected to correlate with grip fatigue, the high correlation with the shirt test was unexpected.

Factor 6, Grip Strength: The grip strength test has by far the highest loading on this factor (.96). Moderate loadings (.50's) from zipping a garment and squeezing toothpaste are also consistent with the identify of this factor.

Factor 7, Manual Dexterity: Managing large buttons (.77) and tying a bow (.90) exhibit the highest loadings on this factor. Two-point discrimination has an intermediate loading (.51). Numerous other tests have modest loadings (.30's). These include the movement time measures, zipping a garment, squeezing toothpaste, Purdue pegboard, and force steadiness supported. It was thus felt that this factor was more closely identified with manual dexterity than with finger dexterity.

Factor 8, Finger Vibration Sense: Factor 8 is best identified from the high loading on the vibration test (.93). Moderate loadings from managing small buttons and pencil rotation and modest loadings from zipping a garment, dialing a telephone, and two-point discrimination are also consistent with a trait for fine finger sensitivity.

Factor 9, Hand Steadiness: The highest loadings on this factor are for resting tremor (.84) and dialing a telephone (.77); but, as might be expected, the two variables are negatively correlated.

Factor 10, Aiming: Hand coordination (.81), putting on gloves (.77) and hand coordination fatigue (-.70) load most heavily on this factor which has also been identified as "eye-hand coordination."

Factor 11, Rate Control: The loading from integrated absolute error (.83) was used as the basis for identifying this factor which reflects the ability of the subject to make "continuous anticipatory motor adjustments relative to changes in speed and direction of a moving target" (Fleishman, 1960). The intermediate weighting (.53) from squeezing toothpaste appears to be due to a flow rate estimate involved in responding to this task. Certain aspects of rate control may also be present in the pencil rotation test (-.40). Moderate loading from 2 point discrimination (.42) is seemingly inconsistent with the identification.

While there are instances where certain factor loadings are not logically consistent, for the most part, good agreement exists between the present results and those reported by Potvin and Fleishman. Most of the factor names and identifications proposed by Fleishman are equally appropriate for the present factors. Finger Dexterity and Manual Dexterity were not as clear cut as could be desired, but Potvin also found that manipulating safety pins and bow tying did not load on the same factor. For the most part, the anomalous loadings are not highly significant and may very well be attributable to statistical fluctuations resulting from the small sample of 20 subjects.

The present study brings out several interesting points relative to the new tracking test measures. The comprehensive nature of the tracking tests is demonstrated by the fact that each of the measures loads heavily on a different factor. The right to left and left to right measures for both reaction time and step movement time are grouped together for the young normal subjects, but this would not necessarily happen for patients with movement disorders. Step reaction time and simple reaction time load nearly equally on Factor 1 suggesting that the former measure may represent a duplication of an already existing test. Movement time appears combined with strength and steadiness and not as a separate factor as was anticipated. A larger sample size or a different subject population could change this relation, however.

The Critical Task and rotary pursuit task both load heavily on the Control Precision factor. The advantages of the Critical Task, such as high reliability and easy mechanization, suggest that it should be considered as a possible replacement for the earlier test. The random tracking error score appears to identify a factor, Rate Control, which was previously lacking in the CQNE.

The finding that the Critical Task and the rotary pursuit task load heavily on the same factor which is distinct from that for Integrated Absolute Error has a reasonable explanation. The first two tasks both involve responses to more or less predictable signals. In the Rotary Pursuit Task, the input is a constant angular rate. For the Critical Task, while there is no forcing function, the subject attempts to compensate

for his own output noise. To that extent, he responds to the effects

of his own previous movements; and shortly after making a strong movement

in one direction he can anticipate having to make a corrective move in

the opposite direction. On the other hand, the random tracking task

requires continuous responses to an unpredictable input and thus re-

quires a different type of psychomotor ability.

While the usual practice in factor analyses is to retain from among

the original tests those providing the best measures of each of the

factors, this was not the intent of the present analysis. Instead, the

principal object was to analyze the interrelationships between the

various test measures and to provide evidence that the new tracking

measures cover approximately the same general area of behavior as the

CQNE and SADLE. In this regard, the tracking tests are more closely

related to the basic CQNE tests than to the more complex SADLE measures

which tend to have loadings well distributed among the various factors.

The findings of the present factor analysis can thus be offered as an

argument for the construct validity of the tracking tasks. Additional

justification for using tracking tests to measure sensory motor

function is given in the next chapter where strong supporting evidence

for the concurrent validity of the new test measures is given.

CHAPTER V

A THERAPEUTIC CLINICAL TRIAL

The purpose of this chapter is to describe the application of the tracking test battery in a therapeutic clinical trial. The trial provided an ideal opportunity for objectively evaluating the usefulness of the tracking tests in assessing modest changes in neurological function. The tracking test battery was administered to 28 parkinsonian patients participating in a randomized, double-blind, crossover trial designed by Walker and his associates (Walker, et al., 1972b) to evaluate the efficacy of amantadine versus placebo in patients already receiving maximally tolerable doees of L-DOPA. The 28 Parkinson's disease patients were randomly assigned to 2 groups, the first receiving L-DOPA + amantadine first and L-DOPA + placebo second, with the second group receiving just the opposite schedule as shown in Table 5.1. Corresponding treatment groups were then combined for analysis.

The tracking tasks provided one of several sets of measures of neurological function. Other measures included qualitative impressions of the patients, professional opinions of the attending neurologists, subjective evaluations of functional disabilities, the Simulated Activities of Daily Living Examination, the Clinical Quantitative Neurological Examination, and a neuro-psychological test battery. A complete description of the other test measures and a complete evaluation of the drug trial can be found elsewhere (Walker, et al., 1972a,b).

TABLE 5.1

EXPERIMENTAL PARADIGM FOR L-DOPA +

AMANTADINE CLINICAL TRIAL

Group	No. of Patients	Medication Taken During Week	
		1 - 3	4 - 6
1	14	L-D + A	L-D + P
2	14	L-D + P	L-D + A

L-D = L-DOPA   A = Amantadine   P = Placebo

Only those results that have direct relevance to the evaluation of the

tracking measures will be considered here.

Numerous investigations of the combined effects of L-DOPA and

amantadine on the treatment of parkinsonism have been undertaken. While

some have shown a beneficial effect from the combination (Voller, 1970;

Fieschi, et al., 1970), others have failed to demonstrate any significant

improvement (Millac, et al., 1970; Green, 1970; Hunter, et al., 1970;

and Godwin-Austin, et al., 1970). The present drug trial was undertaken

because it was felt that many aspects of the previous studies could be

improved. For example, each of the above referenced trials was deficient

in one or several of the following ways:

1. Lack of proper blinding, randomization, crossover.

2. Too few patients evaluated to obtain significance.

3. Failure to use objective measures of motor performance
    and psychomotor skills.

4. The effect of concurrent anticholinergic medication was
    not eliminated.

In spite of the improvements offered by the present trial, however, the
benefits of adding amantadine to L-DOPA were expected to be modest at
best; and the drug trial thus served as a stern test of the sensitivity
and validity of the tracking test battery.

Tracking Measures

A summary of the quantitative tracking measures comparing the
control data obtained from the 15 age-matched normals to the patient
scores obtained after administration of L-DOPA + placebo and L-DOPA +
amantadine is shown in Figure 5.1. The control subjects are found to
perform better than the patients on all the tracking tasks regardless
of the treatment group, although the patients do perform relatively
better on step and critical tracking than on random tracking.

The performance of the combined treatment groups is expressed as a
percentage of matched normal performance and shown in Table 5.2. It is
useful to express patient scores in any drug trial as a percentage of
normal function since it is the goal of the physician to return the
patient's function to the pre-disease level. For example, an improvement
in the random tracking score from 3.36 to 3.04 would be far less meaningful
if the normal control score was found to be 0.50 instead of 1.89.

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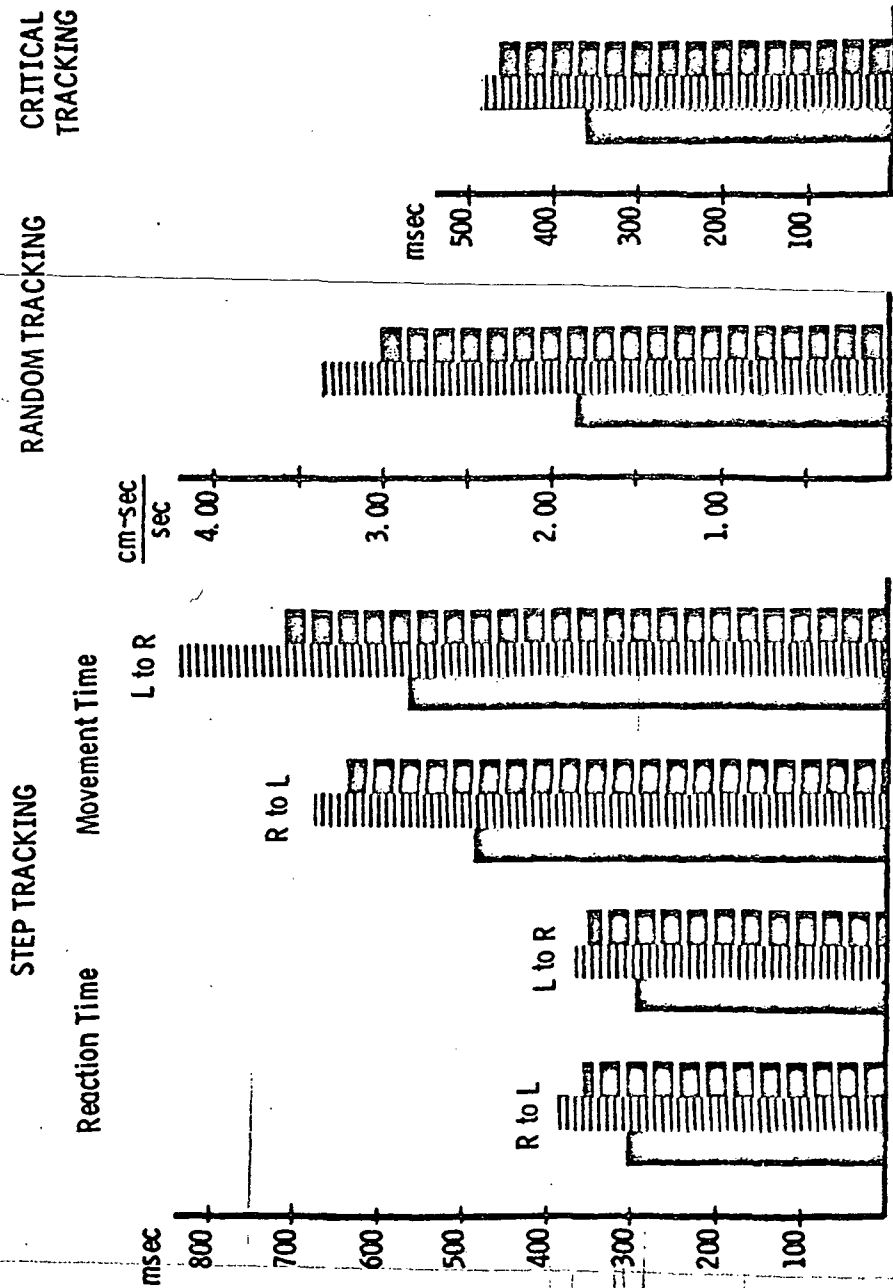
Fig. 5.1 Performance of L-DOPA + Placebo and L-DOPA + Amantadine Treatment Groups Compared with that of Age-Matched Normals for the Tracking Test Measures.

TABLE 5.2

PERFORMANCE OF PATIENTS IN THE TRACKING TEST BATTERY EXPRESSED
AS A PERCENTAGE OF MATCHED ADULT NORMAL FUNCTION

Test	Units	Matched Adult Normal Function Mean ± 2SD	Patients on L-Dopa + P %	SD	Patients on L-Dopa + A %	SD
STEP TRACKING						
Reaction Time, Right to Left	Milliseconds	303 ± 78	83	19	90	22
Reaction Time, Left to Right	Milliseconds	294 ± 67	83	17	86	18
Movement Time, Right to Left	Milliseconds	489 ± 220	78	22	80	20
Movement Time, Left to Right	Milliseconds	568 ± 234	76	22	84	23
RANDOM TRACKING						
Integral of Absolute Error	Centimeter-Seconds / Second	1.89 ± 1.16	61	23	65	17
CRITICAL TRACKING						
Reciprocal of Critical Root	Milliseconds	362 ± 128	78	17	81	18

The fact that the parkinsonian patients perform considerably below
normal is not surprising. Numerous investigators have noted that patients
with parkinsonism have difficulties in initiating responses and are
slow to react to sensory stimuli (Talland, 1963; Dinnerstein, et al.,
1962). Parkinsonian patients have been reported to have particular
difficulty in maintaining continuous movements (Perret, 1968; Perret,
et al., 1970; Schwab, et al., 1954; and King, 1959). The especially
low percent of normal performance for the random tracking task is in
agreement with this finding. Part of the patients' poor performance is
probably due to their longer reaction time. The integrated absolute

error measure is especially sensitive to large deviations from the target.
Not only did the patients have a tendency to occasionally deviate by large
amounts but they also failed to correct immediately. The relatively
better performance by the patients on the Critical Task is an interesting
finding. Part of the improvement may be the result of the test measure,
for the critical root is not as sensitive to the cumulative error as
the IAE score. Another possibility is that the Critical Task is more
motivating than random tracking. A typical remark from one of the
patients was that the test "makes you feel like you've been defeated
when the line goes off the screen." Many patients that appeared bored
with the random tracking task became quite enthused and challenged during
the Critical Task.

As can be seen from Figure 5.1 and Table 5.2, the L-DOPA + amantadine
treatment group demonstrates better performance on all of the tests than
does the L-DOPA + placebo treatment group. Paired-t tests were performed
on the mean differences in performance for the 2 treatment groups. The
results of this analysis are shown in Table 5.3. While all of the
tracking test measures showed improvements favoring the L-DOPA + amantadine
treatment group, only the step tracking (left to right movement time) and
the Critical Task measure showed improvements significant at the 5% level.
While changes in the random tracking scores and right to left reaction
time scores were equal to or greater than 10%, large variations in
these scores among patients prevented these changes from reaching
statistical significance.

TABLE 5.3

RESULTS OF TRACKING TEST BATTERY INVOLVING 28 PARKINSON
PATIENTS: COMPARISON BETWEEN L-DOPA + PLACEBO AND
L-DOPA + AMANTADINE TREATMENT GROUPS

Test	Units	L-DOPA + Amantadine		L-DOPA + Placebo		Difference	% Change	t
		Mean	SD	Mean	SD			
STEP TRACKING								
Reaction Time, Right to Left	Milliseconds	359	91	385	102	27	10	1.61
Reaction Time, Left to Right	Milliseconds	358	84	368	81	10	4	.75
Movement Time, Right to Left	Milliseconds	642	145	679	215	4	7	1.18
Movement Time, Left to Right	Milliseconds	717	191	820	289	10	16	2.32*
RANDOM TRACKING								
Integral of Absolute Error	Centimeter-Seconds / Second	3.04	.74	3.36	1.35	.32	11	1.42
CRITICAL TRACKING								
Reciprocal of Critical Root	Milliseconds	463	96	486	110	22	5	2.23*

* $p < .05$

Concurrent Validity

As pointed out in Chapter I, one of the most important methodological
issues in the evaluation of new test measures is that of validity.
According to Kelly (1969), "the validity of a set of scores refers to
the correctness of the inferences which one makes on the basis of the
scores." In the case of the tracking scores one would infer that the
effects of adding amantadine to L-DOPA are beneficial but modest. The
next step is to determine the appropriateness of this inference by re-
ferring to other established measures of the neurolgoical condition of
the patients. The concurrent validity of the tracking test battery may
be deduced from the extent to which its scores agree with those of the
more established testing procedures.

Patients' Impressions: Nineteen of the 28 patients felt that
L-DOPA + amantadine was superior to L-DOPA + placebo, and 11 of the
patients preferred L-DOPA + placebo to L-DOPA + amantadine, and 4 of

these patients judged it at least 25% better. Four of the patients felt that neither the amantadine nor the placebo treatment offered any improvement in function. None of the patients felt that their functional capacity was worsened by either of the treatments.

Neurologists' Subjective Impressions: Scores on the disability scales (dressing, hygiene, feeding, speech) were all lower on the average, indicating less disability, for the L-DOPA + amantadine treatment group, although no individual category of functional disability was significantly better (Table 5.4). In addition, scores obtained from the standard neurologic examination suggested that the combination of L-DOPA + amantadine improves arm tremor, leg tremor, and gait more than L-DOPA + placebo (Table 5.5).

TABLE 5.4

Comparison of Patient Scores on Disability Scales

For L-DOPA + Placebo and L-DOPA + Amantadine

Treatment Groups

	L-DOPA + Placebo	L-DOPA + Amantadine
Walking	1.9	1.7
Dressing	2.5	2.3
Hygiene	2.8	2.7
Eating	0.88	0.81
Feeding	1.5	1.4
Speech	1.9	1.7

KEY: 1: Mild Disability   3: Severe Disability
     2: Moderate Disability   4: Total Loss of Function

TABLE 5.5

Comparison of Patient Scores on Standard Neurlogical
Examination for L-DOPA + Placebo and L-DOPA + Amantadine
Treatment Groups

	L-DOPA + Placebo	L-DOPA + Amantadine
Tremor, right hand	2.1	1.8*
Tremor, left hand	1.4	1.1
Tremor, right leg	0.8	0.5*
Tremor, left leg	0.5	0.2*
Rigidity, right arm	0.8	0.7
Rigidity, left arm	0.7	0.6
Finger coord., right	1.8	1.7
Finger coord., left	1.6	1.5
Bradykinesia	1.5	1.4
Weakness, right leg	0.4	0.4
Weakness, left leg	0.4	0.3
Rising	1.0	1.0
Posture	1.8	1.6
Stability	1.0	0.8
Gait	1.5	1.3*
Loss of assoc. movt., right	3.6	3.4
Loss of assoc. movt., left	3.1	2.9

* = p < .05

KEY: 1: Mild Disability   3: Severe Disability
      2: Moderate Disability   4: Total Loss of Function

Quantitative Measures: Analysis of the CQNE test scores revealed that the combination of drugs is superior to L-DOPA + placebo for several tests associated with coordination of the hands as shown in Table 5.6. This was also evident for the Simulated Activities of Daily Living Examination, where the combination was significantly better than L-DOPA + placebo for 3 of the 17 tests (Table 5.7). The change in percent of normal function was from 76.7% (L-DOPA + placebo) to 81.6% (L-DOPA + amantadine) on the SADLE. Considering the entire battery of quantitative tests, 94 of the 105 total test measures favored the L-DOPA + amantadine treatment group.

It is helpful for supporting the validity of the tracking test measures to look more closely at the specific tests in the CQNE and SADLE that were shown in Chapter IV to relate to the tracking measures. These relationships were determined with a group of normal young adults so they may not hold as well for older patients with neurological abnormalities. Nevertheless, it is of interest to consider some of the CQNE and SADLE tests in more detail.

Simple reaction time in the CQNE, for example, was found to correlate significantly with step reaction time for the young adult normals (r = 0.40). In the therapeutic trial, the parkinsonian patients had step reaction times well over 100 milliseconds longer than simple reaction times. Since part of the latency in the step tracking task is used for organizing and preparing the execution of a highly skilled response, the size of this difference is reasonable. The general trend for both step reaction time and simple reaction time is the same, namely,

TABLE 5.6
COMPARISON OF PATIENT SCORES ON UPPER EXTREMITY CQNE TESTS
FOR L-DOPA + PLACEBO AND L-DOPA + AMANTADINE TREATMENT GROUPS

Test	Units	L-DOPA +A Mean	SD	L-DOPA + P Mean	SD	Diff	%	t-Diff
Grip Strength	Pounds of Force	52.14	23.54	48.59	23.71	3.55	7.73	2.28 *
Wrist Strength	"	32.91	12.70	31.39	12.96	1.52	4.14	1.94
Shoulder Strength	"	12.45	5.55	11.82	4.66	0.63	2.05	1.61
Reaction Time	msec/.05	12.42	2.85	12.56	2.92	0.14	2.63	0.30
Hand Speed	Taps/10 sec	5.10	0.90	4.92	1.01	0.18	2.03	1.31
Hand Coordination	Taps/10 sec	1.27	0.31	1.30	0.29	0.03	4.44	0.74
Rotary Pursuit	% time on target	41.79	25.01	36.33	25.68	5.46	10.94	1.64
Purdue Pegboard	Pins/30 sec	15.75	6.82	15.04	7.65	.71	5.54	1.38
Pencil	Rotation/10 sec	12.17	5.59	10.70	5.99	1.46	16.72	3.53 *
Grip Fatigue	% fatigue	72.51	10.56	71.46	20.87	1.05	0.53	0.27
Hand Speed Fatigue	"	84.49	12.56	87.06	21.34	2.43	0.87	0.53
Hand Coordination Fatigue	"	87.52	18.80	78.36	22.54	9.16	8.71	2.07 *
Vibration Sense	Micron/10	0.39	0.32	0.43	0.42	0.07	9.33	0.86
2 Point Discrimination	Millimeters	4.54	0.58	4.61	0.74	0.07	2.44	0.49
Force Steadiness Supported	Gram-Sec/Sec	13.46	21.73	14.18	19.81	0.72	4.63	0.26
Force Steadiness Unsupported	"	27.94	73.89	31.52	70.02	3.58	10.52	0.75
Resting Tremor	G-Sec x .01 / Sec	31.58	50.99	49.46	62.55	17.87	36.31	2.58 *
Sustention Tremor	"	19.74	38.91	12.56	23.60	-7.18	-11.83	-1.35

* = p < .05

TABLE 5.7

Comparison of Patient Scores on SADLE for L-DOPA + Placebo

and L-DOPA + Amantadine Treatment Groups

Test	L-DOPA + A		L-DOPA + P		Diff	%	t - DIFF
	Mean	SD	Mean	SD			
Shirt	46.18	74.21	58.51	91.29	12.33	32.96	1.27
Large Button	9.91	5.45	14.74	22.11	4.82	34.66	1.26
Small Button	14.61	21.73	23.96	35.42	9.35	64.67	1.83
Zipper	5.62	3.89	6.80	6.19	1.18	19.08	2.08 *
Bow	19.04	19.82	30.57	36.46	11.53	42.71	2.42 *
Cutting	14.57	6.06	20.73	21.11	6.16	44.04	1.62
Fork	2.77	0.81	3.17	1.62	0.40	11.43	1.95
Toothpaste	10.15	6.59	8.93	4.01	1.22	1.05	1.17
Dialing	18.79	14.79	16.51	6.22	2.27	.18	0.77
Safety Pin	8.13	5.97	14.47	24.52	6.35	67.85	1.42

* = p < .05

** = p < .01

to favor the L-DOPA + amantadine treatment group. The step tracking measure showed a greater percent change favoring this treatment, however, and appears to be a slightly more sensitive measure than simple reaction time. This is especially true for the right to left movement where the patients were moving the control stick toward their body and probably exercised the most caution.

The movement time measures for the step tracking task were found to correlate with a number of strength and steadiness measures as well as with the SADLE test requiring cutting with a knife in the young normal population. In the therapeutic trial only step movement time for a left to right transition showed a statistically significant improvement with L-DOPA + amantadine, although all the other measures did show improvements favoring this treatment. It is interesting to note, however, that with the young normal group, movement time and steadiness were negatively correlated indicating that the faster a person is the less steady he will tend to be. If this same relationship held with the parkinsonian patients, their improvement in speed should have corresponded to a decrement in steadiness, which was not the case. Because of the pathological tremor demonstrated by many of the patients, it is fair to assume that the steadiness tests were probably measuring different functions than with the young normal group.

While the random tracking task measure stood somewhat alone as the major identifier of a Rate Control factor, it did have moderate correlations with pencil rotation (r = 0.42) and squeezing toothpaste (r = 0.35). All of these measures showed improvement with L-DOPA + amantadine, but only the pencil task change in performance reached statistical significance.

The Critical Task, rotary pursuit, and supported force steadiness were used to identify a Control Precision factor. Only the Critical Task scores showed significant changes, however. The main reason for this appears to be the much lower performance variability with this task than with the others.

It is thus found that there is general agreement between the
majority of qualitative and quantitative measures and the tracking
battery. Furthermore, in comparing all measures of performance involving
the upper extremity, the tracking tests were found to be at least as
sensitive to the performance changes observed between the two treatment
groups as the most sensitive quantitative measures of either the
Clinical Quantitative Neurological Examination or the Simulated Activities
of Daily Living Examination.

CHAPTER VI

PHASE PLANES AND POWER SPECTRA

The purpose of this chapter is to consider the application of two frequently used systems engineering techniques, phase plane diagrams and power spectral density functions, for describing the tracking behavior of patients with neurological disorders. Samples from the tracking records of 35 normal subjects, ages 18 to 74 years, and 35 patients demonstrating movement disorders with previous neurological diagnoses of multiple sclerosis, Parkinson's disease, and cerebral palsy were examined using these techniques. Representative time records and phase plane diagrams for the step tracking task and time records and power spectra of the tracking error for the random tracking task are presented. In that the sample size is small and the application of these techniques is new, most of the discussion will be devoted to qualitative inferences.

Introductory Description of Phase Planes and Power Spectra

A phase plane trajectory is simply a plot of velocity versus position with time as a parameter (Graham and McRuer, 1961, and Levinson, 1962). In engineering applications the chief value of the phase plane approach lies in the fact that the trajectories, which represent the transient behavior of a system, can often be determined even though the exact relationship between position and time is unknown.* In this paper phase plane trajectories were obtained by plotting know values of

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*Analysis is limited to first- and second-order systems.

velocity against known values of position. The velocity and position signals were recorded on magnetic tape and then played back at a reduced speed on an X-Y plotter. A hypothetical phase plane diagram is shown in Figure 6.1. Phase trajectories have a definite direction associated with them; for when the velocity is positive the path must go to the right, and when the velocity is negative the path must go to the left. Crossovers on the velocity axis indicate overshoots in the response function.

Even when the time behavior is already known there is still merit to examining performance in the phase plane. This is especially true when families of trajectories are examined. Testing with humans is normally subject to considerable variability even when performance for the same individual is concerned, and this is even more true for patients with neurological disorders. Plotting several phase plane trajectories on the same graph provides a compact way of displaying the variability in step responses at the same time that it clearly illustrates characteristic movement patterns.

The phase plane method is a time domain technique because it deals with signals that are expressed as functions of time. Power spectral densities, on the other hand, represent behavior in the frequency domain. Frequency domain analysis is based on the fact that waveforms of the type we are concerned with can be synthesized from a series of sinusoidal components. The concept of frequency and the components of frequency arose from a musical context (Scott, 1960). Musical scales are built around the harmonics of a given tone, and musical chords depend on the

Velocity

PHASE PLANE

For positive velocity the trajectory goes to the right

t=3 t=4

Position

t=2

Phase Trajectory

Crossovers indicate overshoots

t=1

For negative velocity the trajectory goes to the left

Position

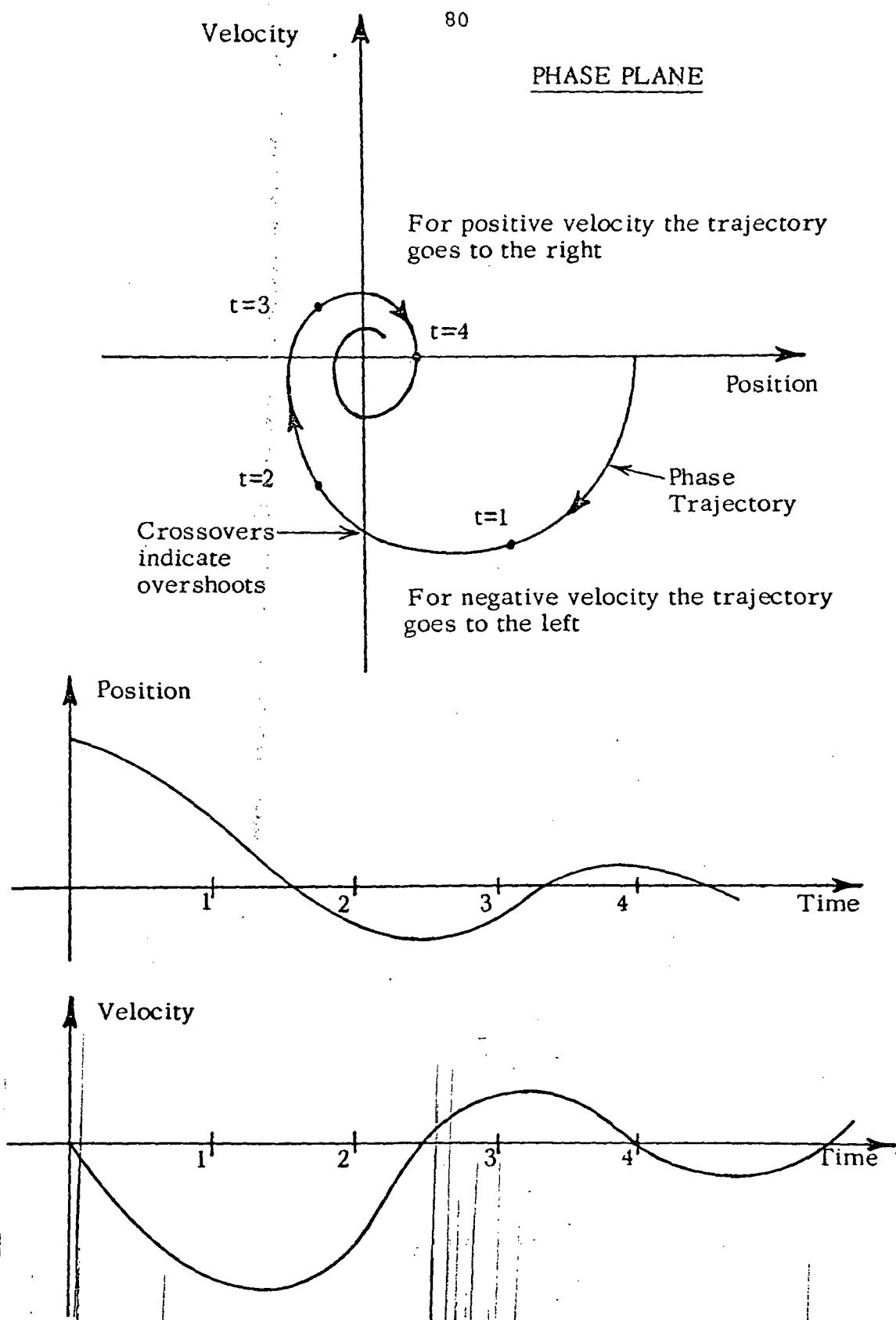1   2   3   4   Time

Velocity

1   2   3   4   Time

Fig. 6.1.   Phase Plane Diagram and Corresponding Time Traces.

resolution of complex sounds into individual components. Similarly,

the task of frequency analysis is to resolve a complex waveform into

sinusoidal components of different frequencies and then to represent

the waveform in terms of the characteristics of the individual sinusoids

(see, for example, Licklider, 1951). The square wave of Figure 6.2

is a good example to consider for this type of analysis. This waveform

can be represented by a fundamental component and a series of odd

harmonics of varying amplitudes. Even with the two components shown

in the figure, it is apparent that the square waveform is being approached.

By adding more and more components together it is possible to bring the

sum arbitrarily close to the square waveform. The term "density" is

used because the area under the function over all frequencies from zero

to infinity is the total "power" in the waveform. The power density

functions thus illustrate the dominant frequency ranges in a signal which

contribute to its overall mean-square value. Detection of periodicities

can be noted in the power spectral density function by the presence of

sharp peaks at discrete frequencies (see Bendat, 1962).

Since the frequency domain concept may be difficult to grasp for the

uninitiated, time histories of a sinusoidal function, narrow-band noise,

and wide-band noise, along with the corresponding power spectral density

functions are shown in Figure 6.3. For the sinusoidal function, the

mean-square power is concentrated at a single frequency. In the case of

narrow-band noise, the power spectral density function is centered at a

particular frequency and then rapidly approaches zero on either side.

A resting tremor of somewhat varying amplitude in a narrow frequency

Square Wave
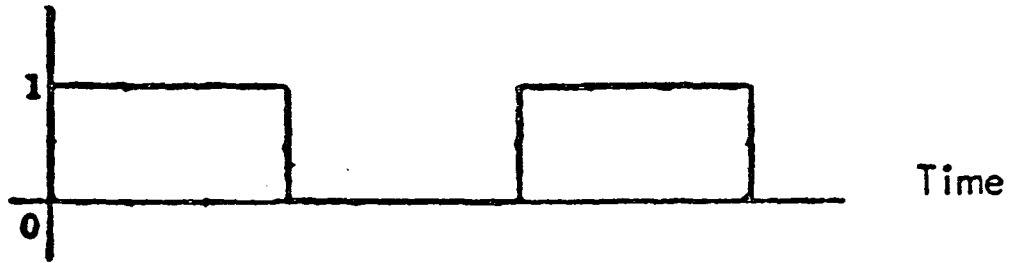
D-C Value, Fundamental, and Third Harmonic
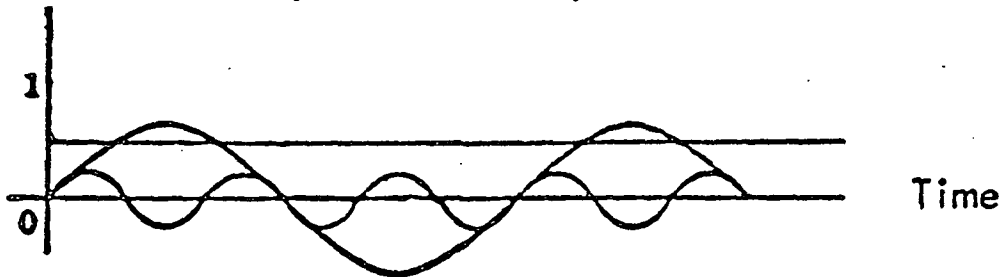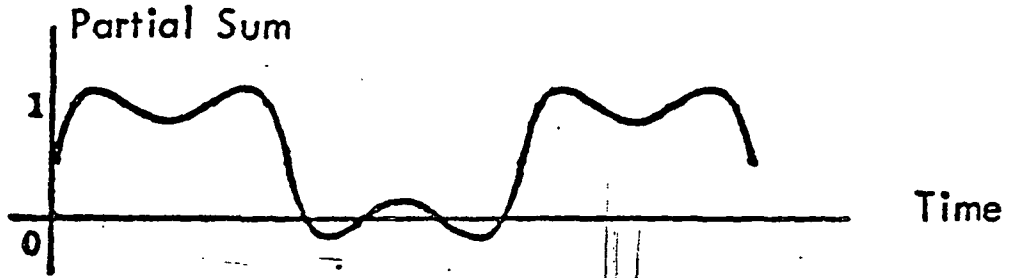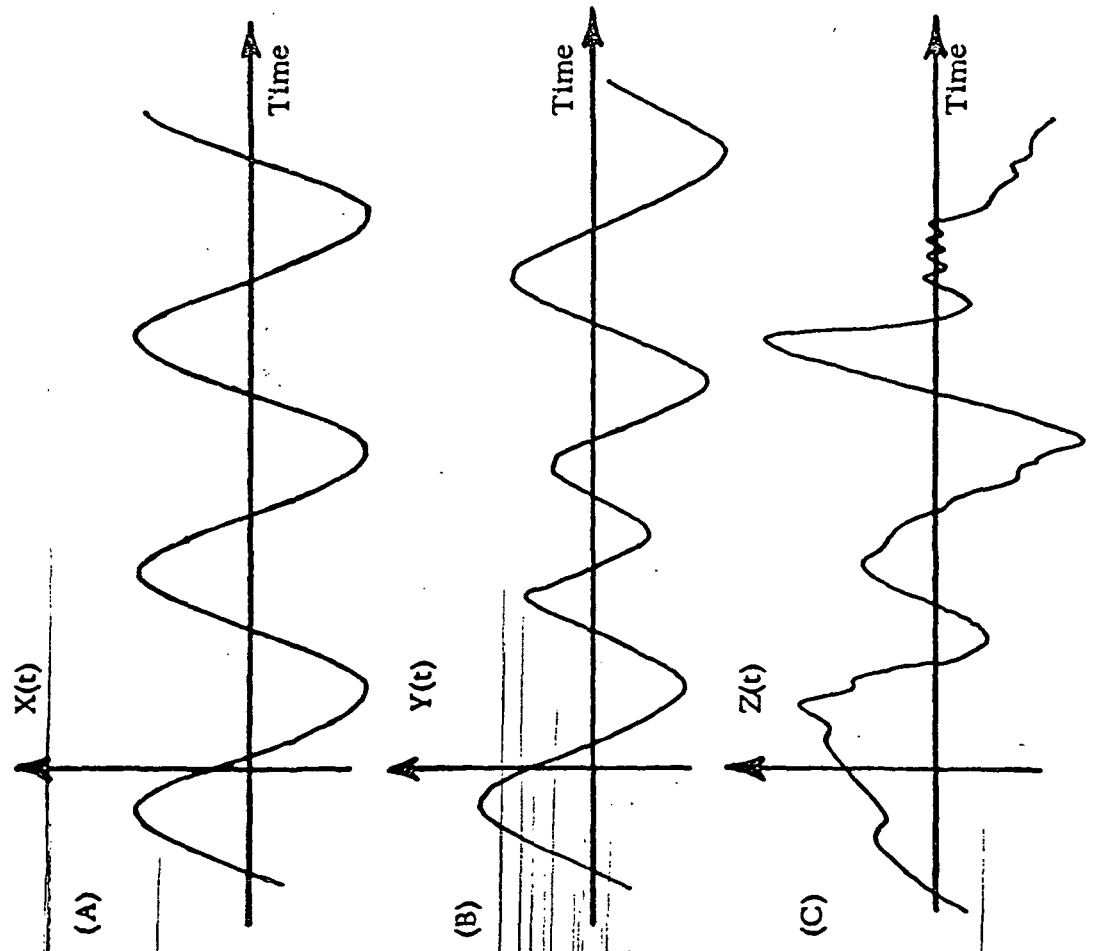

Partial Sum

Fig. 6.2. Resolution of a Square Wave into Sinusoidal Components.

83

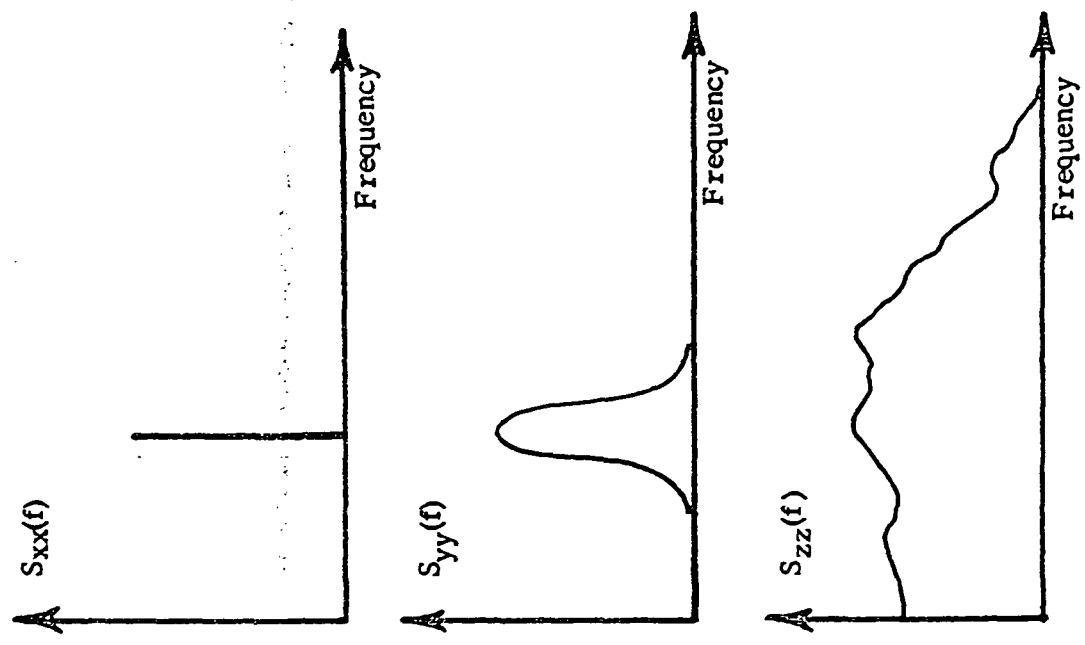POWER SPECTRAL DENSITY FUNCTIONS

TIME HISTORIES

Fig. 6.3. Time Histories and Corresponding Power Spectral Density Functions for 3 Commonly Encountered Signals.

range could produce a similar time history. For wide-band noise, there is no concentration at any particular frequency and the power spectral density function is spread out over a large frequency range.

The power spectral density functions for random tracking error were obtained by first computing an autocorrelation function and then computing the Fourier transform of this function to obtain the desired spectral representations (see Appendix D and Stern, 1971 for details). While the absolute levels of the spectra shown are arbitrary, the power spectra are not normalized, thus allowing comparisons between the power in db for any given subject and the power at the same frequency for any other subject.*

Results

While quantitative indices of tracking performance are useful in evaluating the effects of different types of therapy, spatial-temporal response records provide a more complete source of information on tracking performance. Such records preserve the interesting movement characteristics and often provide a basis for hypotheses which further the understanding of motor performance. Furthermore, inspection of graphic records often provides the rationale for choosing among different possible quantitative indicants. With these thoughts in mind, phase

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*The db or decibel scale is a logarithmic form of the power density scale. Thus, if the power density level P_1 at frequency f_1 is 10 times the level P_2 at frequency f_2, then P_1 is said to be 10 db greater than P_2. If P_1 is 100 times P_2, then P_1 is 20 db greater than P_2.

plane diagrams and power spectra were used to characterize the tracking performance of patients with various movement disorders.

Phase Plane Diagrams

Figure 6.4 illustrates typical step response patterns for four subjects with widely varying neurological conditions. The initial starting point is at a position of 40 degrees and the desired end point is at 0 degrees. Each response pattern will be considered individually.

1. Young adult normal: The step response is rapid and precise and exhibits a single small overshoot.

2. Multiple sclerosis patient with moderate to severe intention tremor: Classical intention tremor which appears only during active movements is clearly demonstrated here. No tremor is present at rest or during the early part of the movement; but as the target is approached, oscillations appear and then persist for several seconds after the target region has been reached. The step response is somewhat violent, the tremor is coarse, and the patient has considerable difficulty in settling on the exact target position.

3. Parkinsonian patient with severe resting tremor: A classical form of resting tremor is shown in this response. The tremor becomes manifest at rest and ceases during voluntary movement. There is a characteristic delay of several seconds between the stoppage of the movement and the reappearance of tremor. The tremor begins with small amplitude oscillations and reaches its accustomed level within a few cycles.
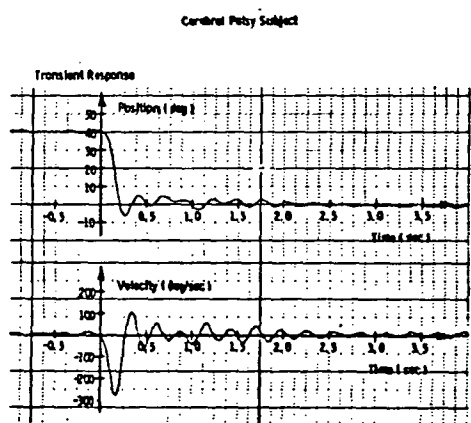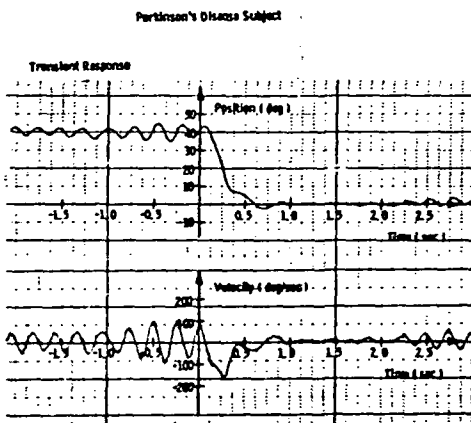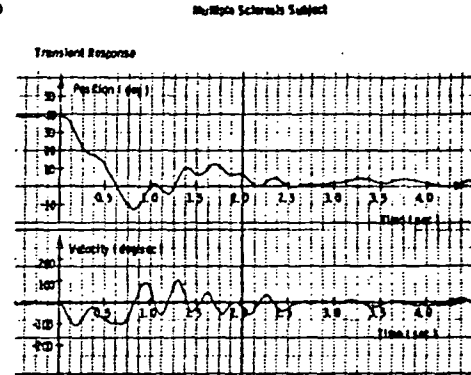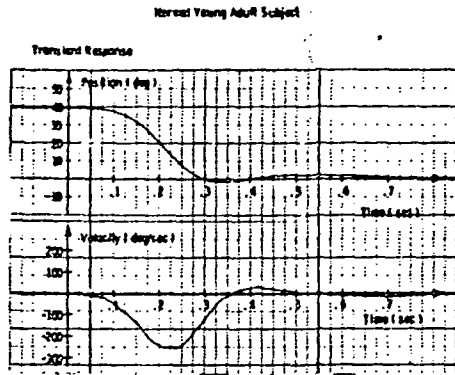
Fig. 6.4 Time Records and Phase Plane Diagrams Characterizing the Step Tracking Performance of Representative Patients and Normals.

4. Adult cerebral palsy patient with mild intention tremor and
    slight resting tremor: The step response is rapid and precise
    except for mild oscillations at the end of the movement. These
    oscillations settle down to a low amplitude tremor which remains
    at rest.

Figure 6.5 shows families of trajectories for four normal young
adult subjects. These trajectories are for both right to left and left
to right movements. The starting point for the right to left movement
is +40 deg. and the target point is 0 deg., while for the left to right
movement they are just the opposite. While there is considerable
variability in peak velocities between subjects, intra-subject variability
is low. A single, small overshoot is characteristic of most of the
responses.

Families of trajectories for six multiple sclerosis patients are
shown in Figure 6.6. The patients are listed according to a physician's
subjective evaluation of their intention tremor, from slight to moderate-
severe. It is important to note that this evaluation was made prior to
the time the patients were tested with the tracking battery. The move-
ment patterns vary from those that are only slightly different from
normal to patterns that show coarse and violent oscillations about the
target point.

The information contained in these plots can be transformed into
quantitative measures. For example, in the parkinsonian study considered
in Chapter V, a movement time measure was used which was based on the
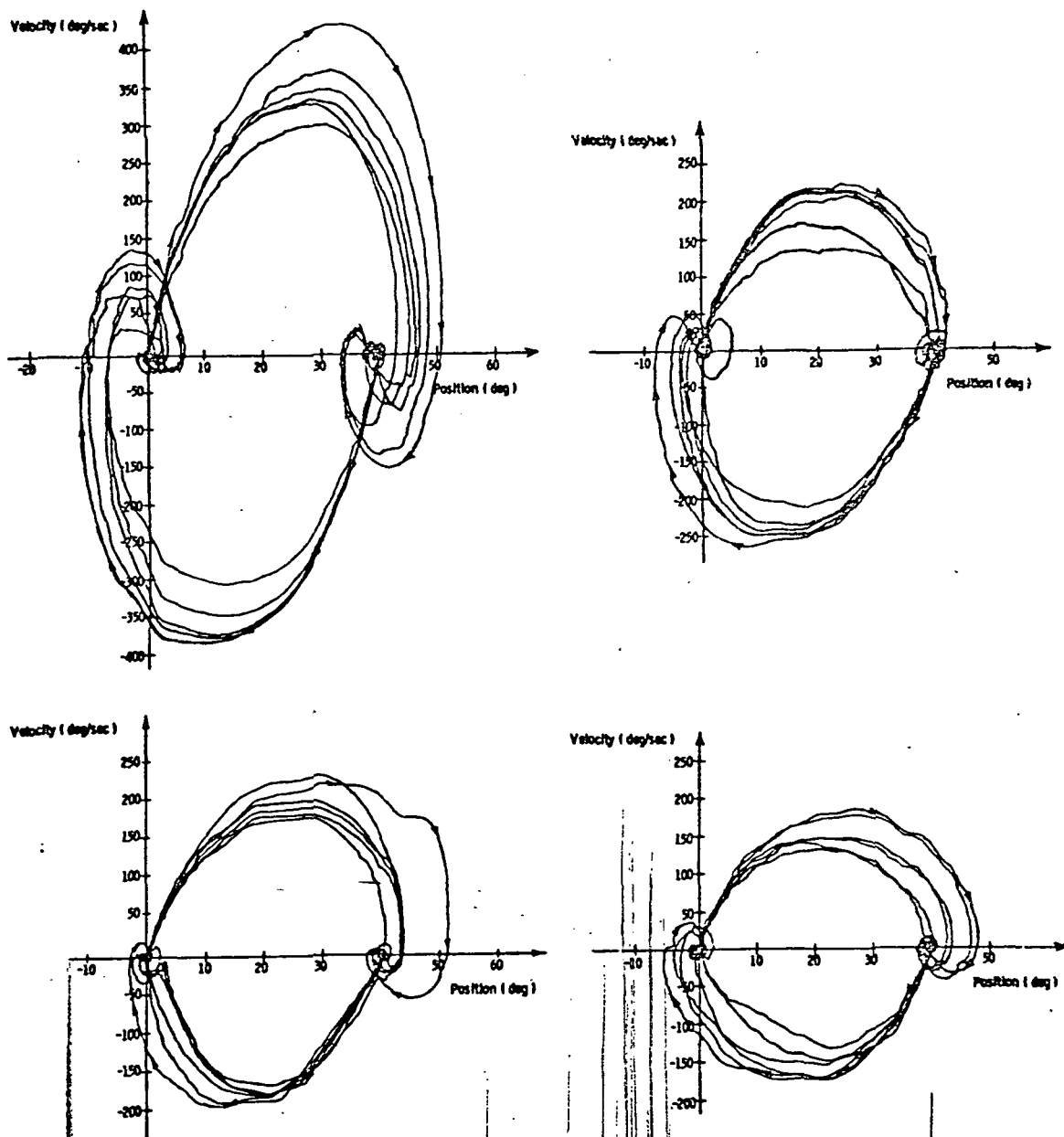time between the first large move away from zero in the velocity record

Fig. 6.5. Phase Plane Trajectories of 4 Normal Young Adults.
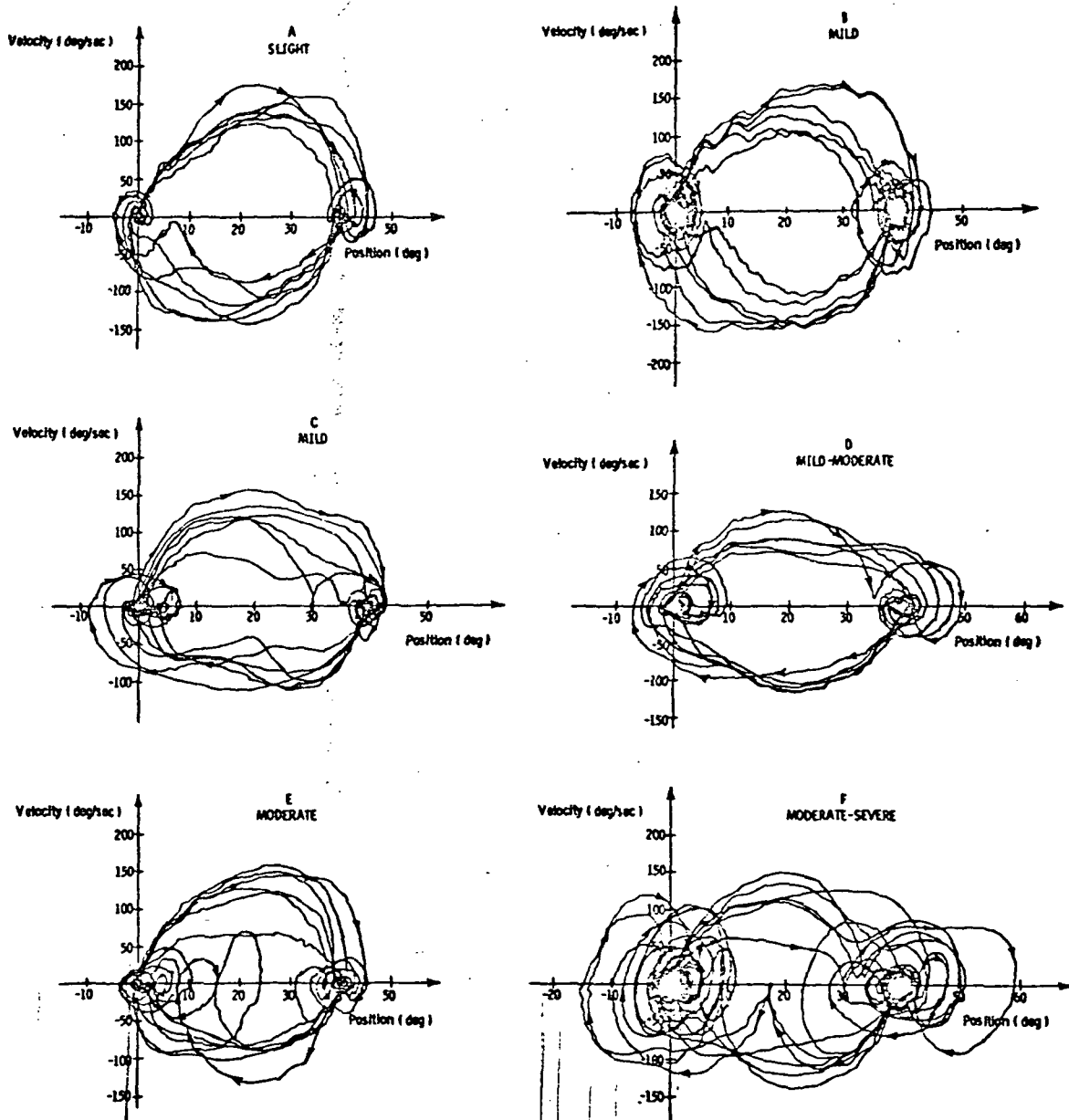
Fig. 6.6.   Phase Plane Trajectories of 6 Multiple Sclerosis Patients.

and the return to zero. While movement time is a meaningful measure

of step tracking performance for normals and parkinsonian patients,

inspection of the phase plane diagrams for multiple sclerosis patients

suggests that additional measures are required to effectively describe

this performance. The neurologist's evaluation of intention tremor is

based on a subjective weighting of different aspects of the speed and

accuracy of a movement toward a target, as in the finger-to-nose test.

Movement time, decomposition, overshoots, and oscillations about the

target all enter into his evaluation. Control engineers use a number

of precise performance measures for judging the step responses of

physical systems which are equally appropriate for quantifying movement

disorders in a step tracking task. Time delay and rise time are two

measures that are closely related to reaction time and movement time.

More important measures, as far as intention tremor is concerned, are

peak overshoot and settling time. Peak overshoot is the largest negative

error between input and output during the transient state. On the phase

plane diagram for the moderate-severe multiple sclerosis patient this

corresponds to 19 degrees for a left to right movement and 15 degrees

for a right to left movement. A typical female normal, Figure 6.5(b),

has a left to right peak overshoot of 2 degrees and a right to left peak

overshoot of 8 degrees. Settling time is the time required for the

response to decrease and stay within a specified percentage of its final

value, typically 5%. For the multiple sclerosis patient shown in

Figure 6.4, the settling time is 3.8 seconds while for the normal young

adult in the same figure it is only 0.28 seconds. Inspection of the

phase plane trajectories for multiple sclerosis patients strongly

suggests that the neurologist is also influenced by these performance

measures in making his rating and that these measures can provide a

meaningful and objective characterization of patient performance.

Attempts to obtain a quantitative measure of the finger-to-nose

test have previously proved unsuccessful. Part of the difficulty now

seems apparent. Performance in this test is multidimensional in nature

and unless a psychomotor test contains the same type of performance

dimensions, high correlations will not be found. Although the small

number of multiple sclerosis patients studied precludes the use of

statistical correlations, the phase plane features do appear to be in

close agreement with what the neurologist can see.

Power Spectral Densities

Power density spectra basically describe the statistical behavior

of random functions in terms of the frequency domain. Error patterns in

the random tracking task were analyzed using this technique. Error

patterns were selected because they are concerned with the realtions

between the desired response and the actual response, and skilled motor

behavior is more concerned with this relation than with the response

pattern itself. Spectral densities were used because the traditional

measure, integrated absolute error (IAE), fails to account for the actual

movement patterns present in the error signal. Two subjects may have

identical IAE scores but completely different error patterns. In addition,

power spectral densities are less sensitive to transient and infrequent

lapses in tracking accuracy which are often the cause of large variability in IAE scores for the same subject.

Figure 6.7 shows error power spectra for four normal control subjects. Based on previously obtained IAE scores, these control subjects span the range of performance found for the normal groups. The shapes of the spectra are basically similar with no sharp peaks. The fact that the two older control subjects have the highest and lowest low frequency power levels is worth noting. The variability in performance for the group of 15 older normals was much greater than for the 20 young normals. Error records for the four subjects are shown in Figure 6.8.
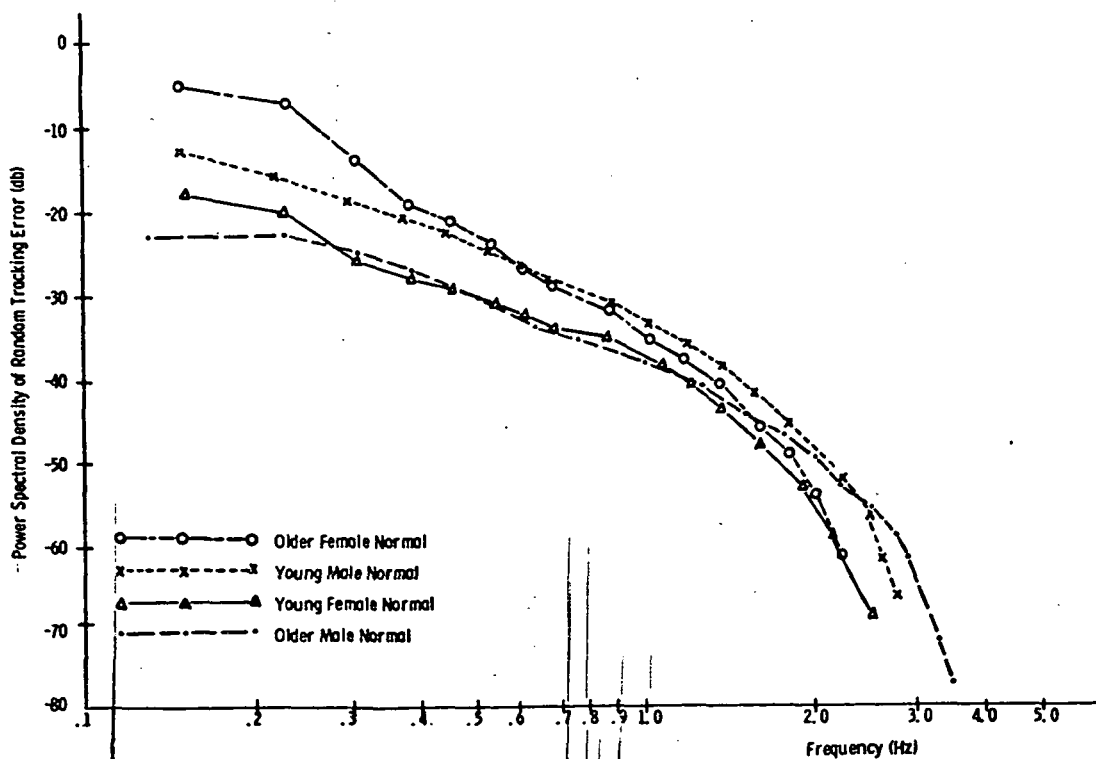

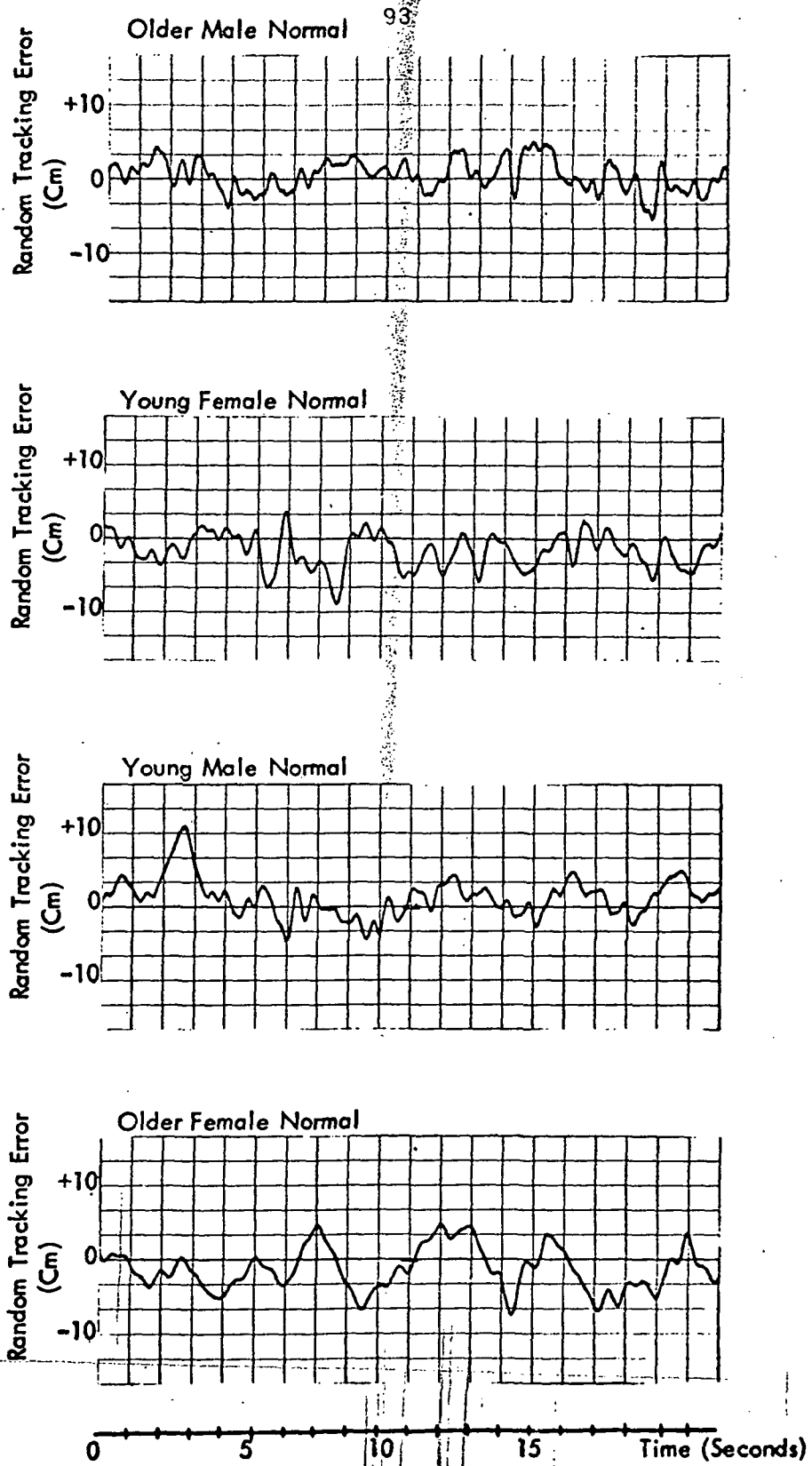Fig. 6.7. Error Power Spectra for 4 Representative Normal Subjects.

Fig. 6.8.   Tracking Error Time Histories for 4 Representative Normal
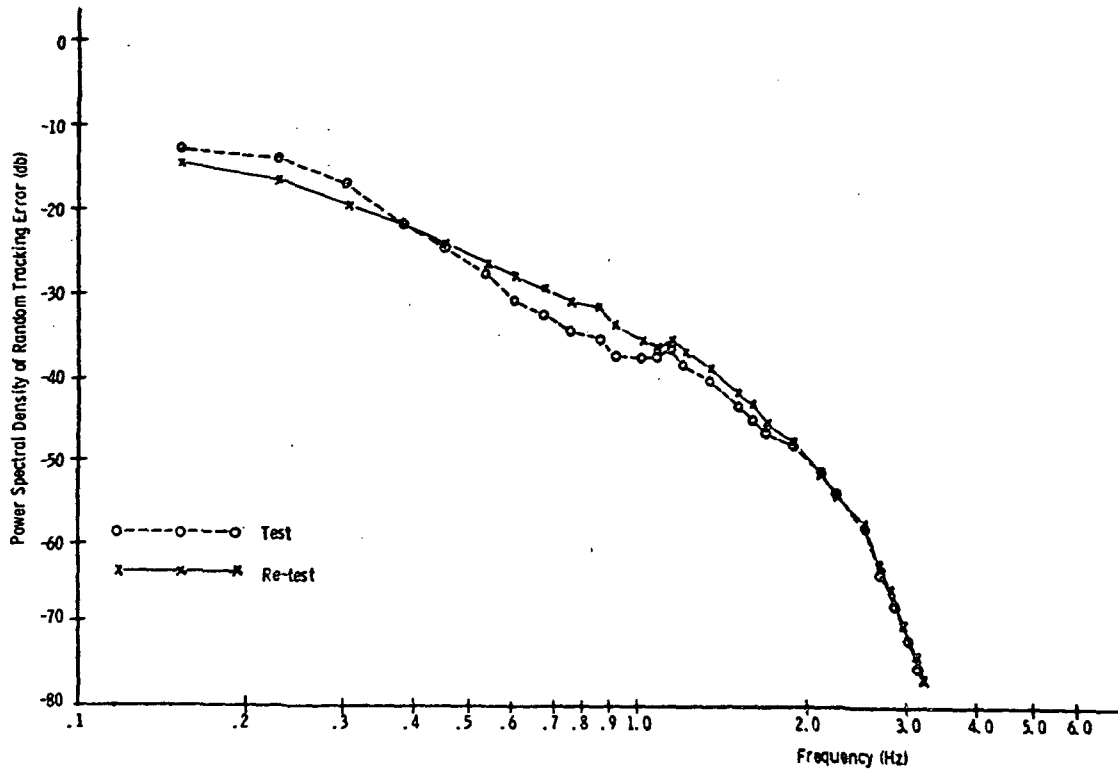   Subjects.

Fig. 6.9.   Error Power Spectra for a Normal Subjects in a Test-
            Retest Study.

Figure 6.9 shows the error power spectra obtained from the same

older normal on two separate occasions three weeks apart.   There is

good agreement between the two sets of measurements especially at

higher frequencies.   The group of older normals tended to improve their

performance when retested, i.e., they reduced their power density levels,

but the trends were not statistically significant based on IAE scores

(see Chapter III).

The error power spectra for three patients with widely varying

neurological disorders are shown in Figure 6.10.   The multiple sclerosis

patient had a slow, coarse intention tremor which did not result in any
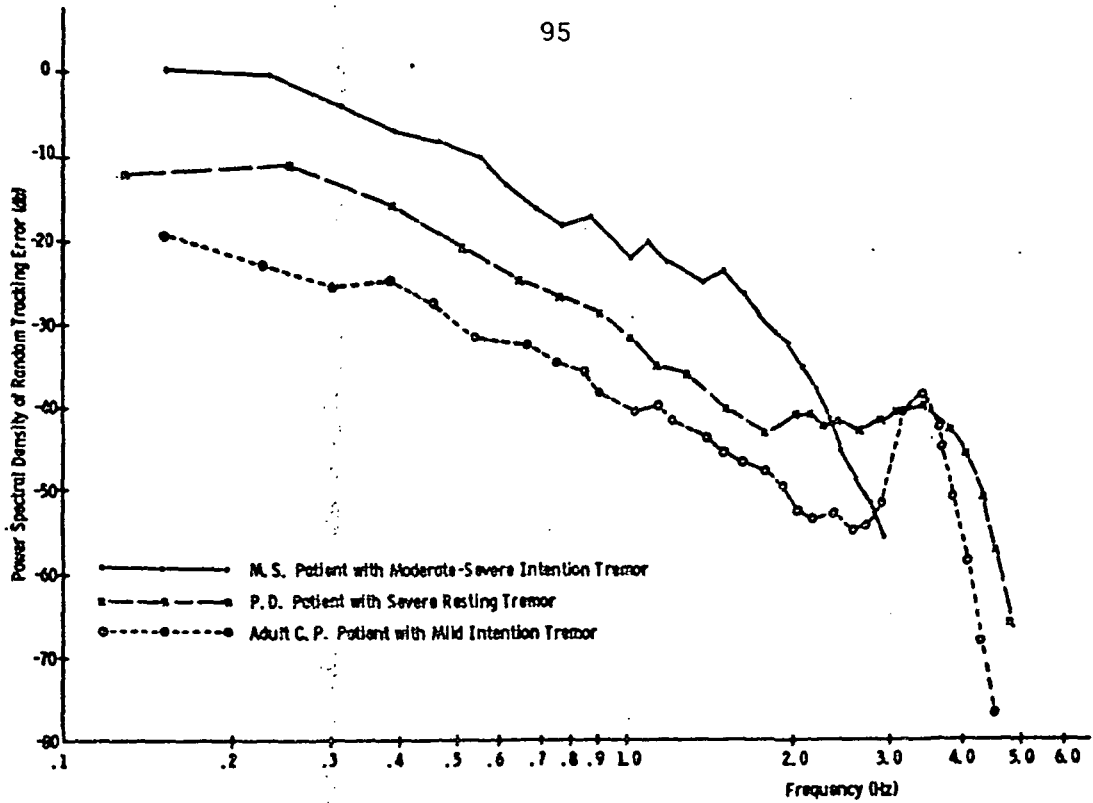
Fig. 6.10 Error Power Spectra for 3 Patients with Different Neurological Disorders.
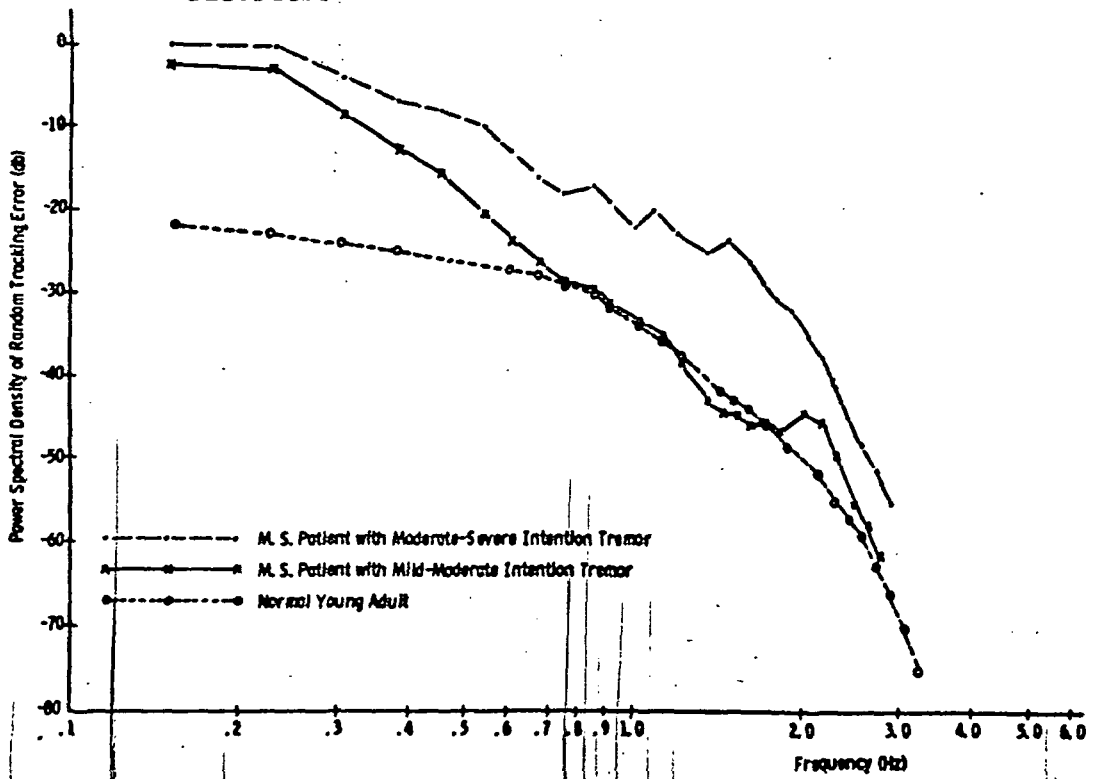

Fig. 6.11. Error Power Spectra for 2 Multiple Sclerosis Patients Compared with a Normal Subject.

sharp peaks in the error spectrum. The slowly moving random target

signal did not require limb movements sufficiently rapid to always

suppress resting tremor in the parkinsonian patients. As a result,

the power spectrum for the parkinsonian patient has a rather broad peak

in the 3 to 4 hz range indicating that his resting tremor appeared

only intermittently during the tracking task. In contrast, the cerebral

palsy patient had a very regular, small amplitude tremor throughout

the random tracking trials. This resulted in a very decided peak at

about 3.5 hz.

The fact that the rhythmic character of some tremors is more

obvious than that of others is clearly illustrated by these spectra.

In general, tremors are composed of waves of different frequencies and

amplitudes. If a particular frequency is dominant and persistent, as

in the case of the cerebral palsy patient, the tremor appears to be

extremely regular. On the other hand, if no particular frequency

is dominant or if the frequency and amplitude patterns are changing,

then an irregular rhythm is apparent.

Figure 6.11 compares the power spectra for 2 multiple sclerosis

patients with that of a normal young adult. The differences in the

power density levels at the low frequency end of the spectra are striking

The patient with the previously diagnosed intention tremor of mild to

moderate does show a slight peak at around 2 hz,

Figure 6.12 shows the power spectra for a parkinsonian patient

taking part in a drug trial designed to compare the efficacy of L-DOPA

+ amantadine to that of L-DOPA + placebo. This particular patient had

severe hypokinesia and a severe resting tremor which did not cease

during the tracking task and which was not affected differentially by

the two treatments. There is a slight overall improvement with the

L-DOPA + amantadine treatment combination, however. This improvement

is not caused by learning as amantadine was administered first.

Figure 6.13 compares two parkinsonian patients with an age-matched

control subject. The patient with severe hypokinesia has a very rapid

fall-off in error power density with frequency and very high power

density at the low end of the spectrum. This type of characteristic

indicates that the patient made predominantly slow, smooth motions and

very few quick, corrective movements. The other parkinsonian patient

had a severe resting tremor which appeared intermittently during

voluntary movement, thus producing small peaks around 2.5 and 3.5 hz.

Figures 6.14 and 6.15 show error traces for each of the patients described

above.

While the intent of the random tracking studies and the subsequent

spectral analysis was not to investigate the mechanisms of tremor, an

interesting observation can still be made in this regard. A number of

investigators have studied the effect of increasing the moment of inertia

of the vibrating body part on the frequency of tremor (see Stiles and

Randall, 1967 for a brief review). Both supporting and nonsupporting

evidence for a mechanical mechanism of tremor have been given. Some

investigators have found little or no change in tremor frequency with

added mass while others have reported definite decreases in frequency

which would be expected if the tremor were strongly influenced by the
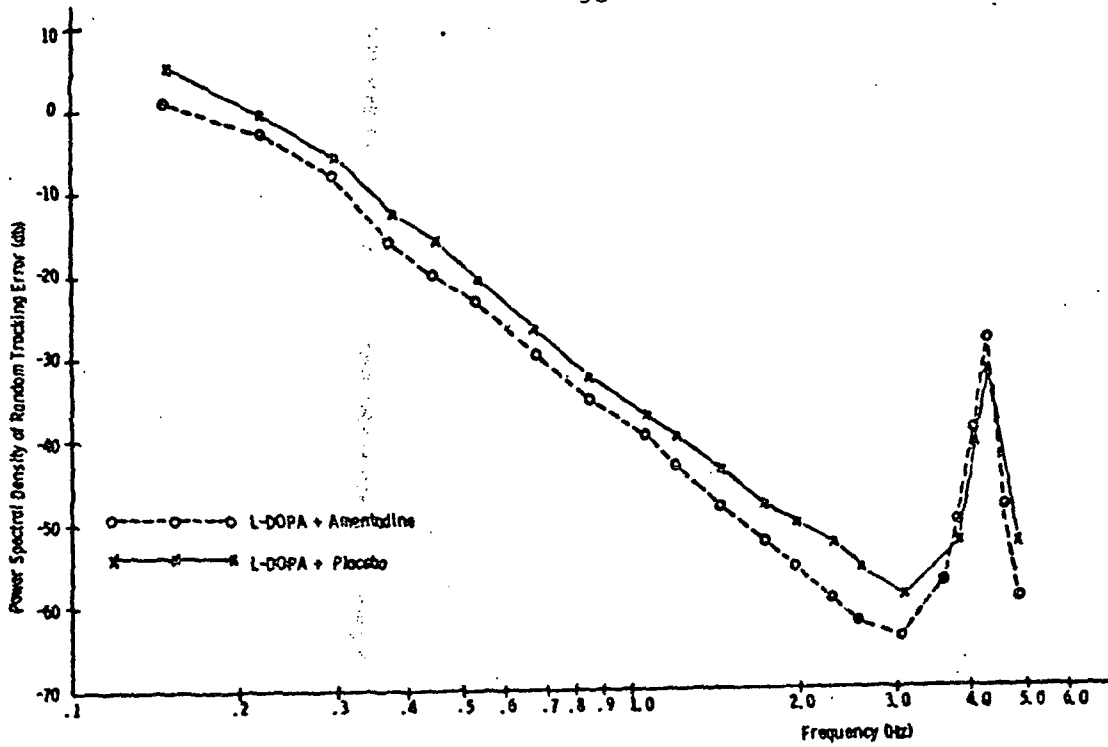
Fig. 6.12 Error Power Spectra for a Parkinsonian Patient Participating in L-DOPA and Amantadine Drug Trial.
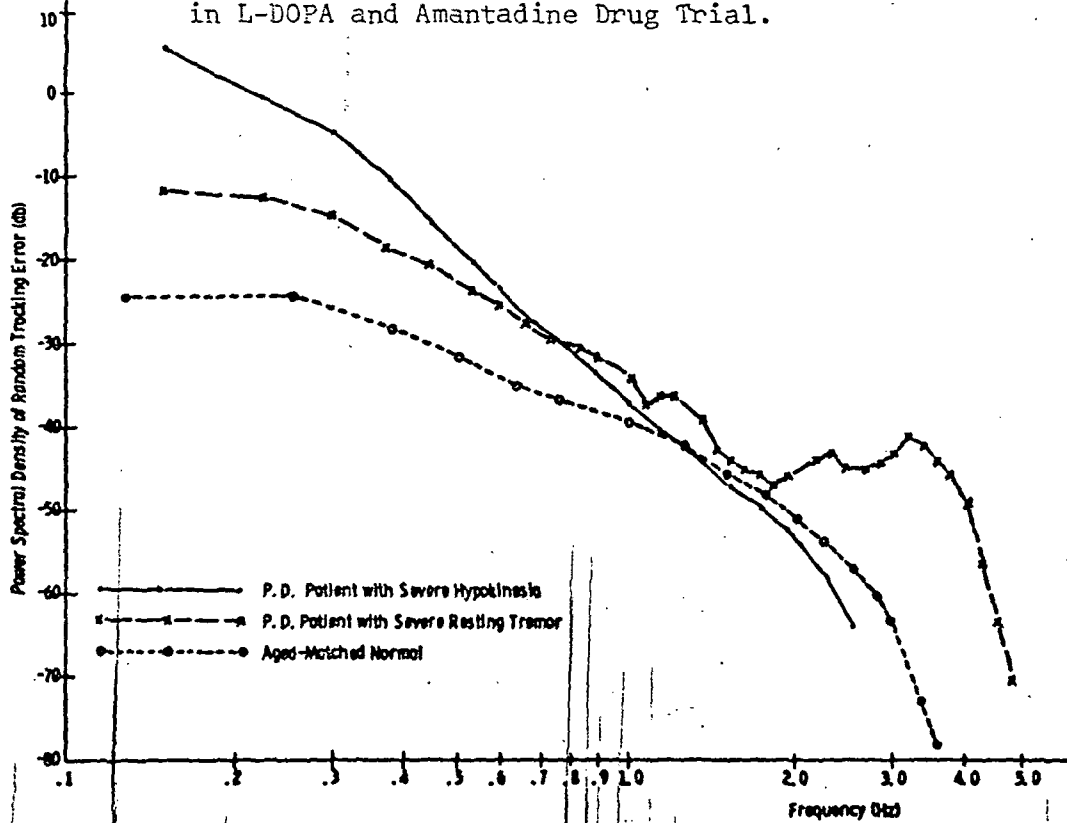
Fig. 6.13 Error Power Spectra for 2 Parkinsonian Patients Compared with an Age-Matched Normal Subject.

Fig. 6.14 Tracking Error Time Histories for an Adult Cerebral Palsy Patient and 2 Multiple Sclerosis Patients.

P.D. Patient with Severe Resting Tremor and Severe Hypokinesia

P.D. Patient with Severe Resting Tremor

P.D. Patient with Severe Hypokinesia

Fig. 6.15 Tracking Error Time Histories for 3 Parkinsonian Patients.

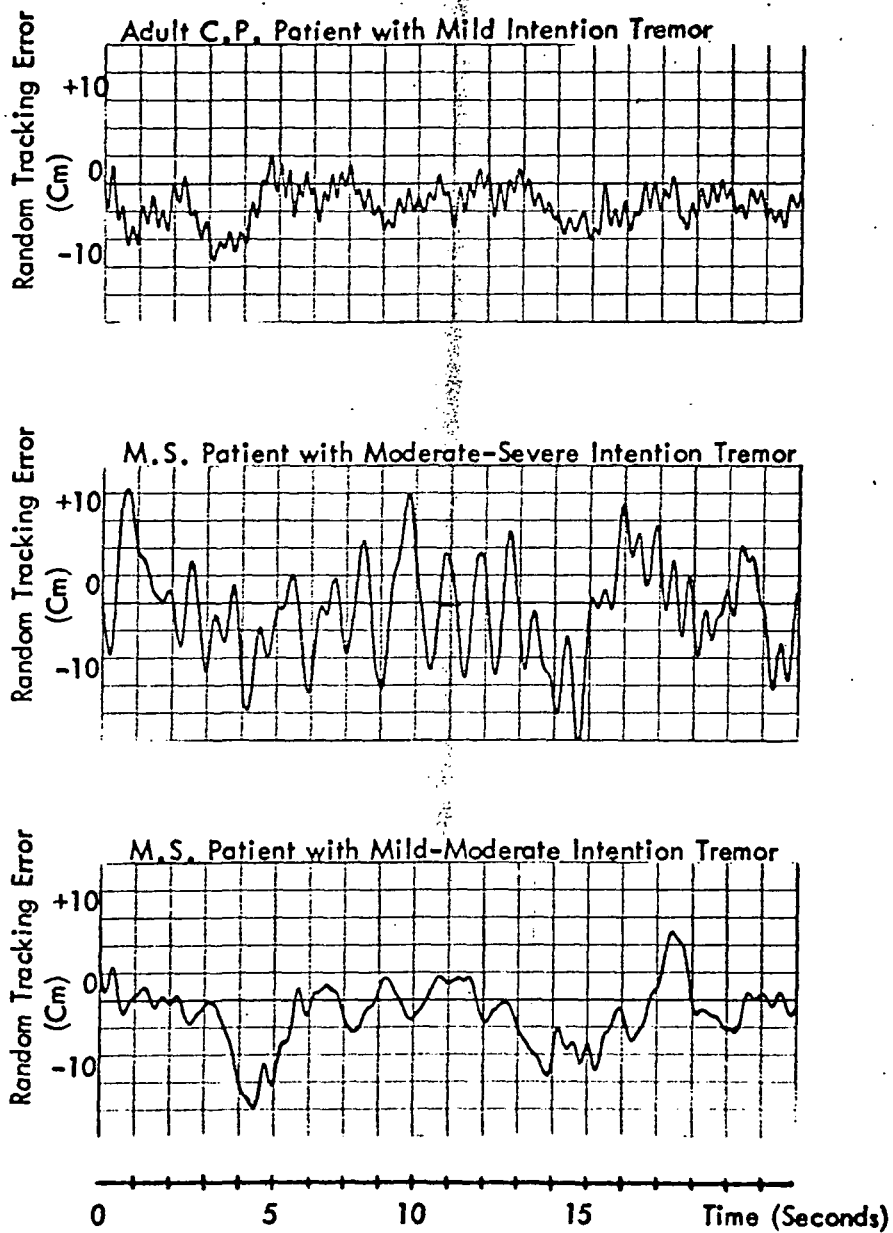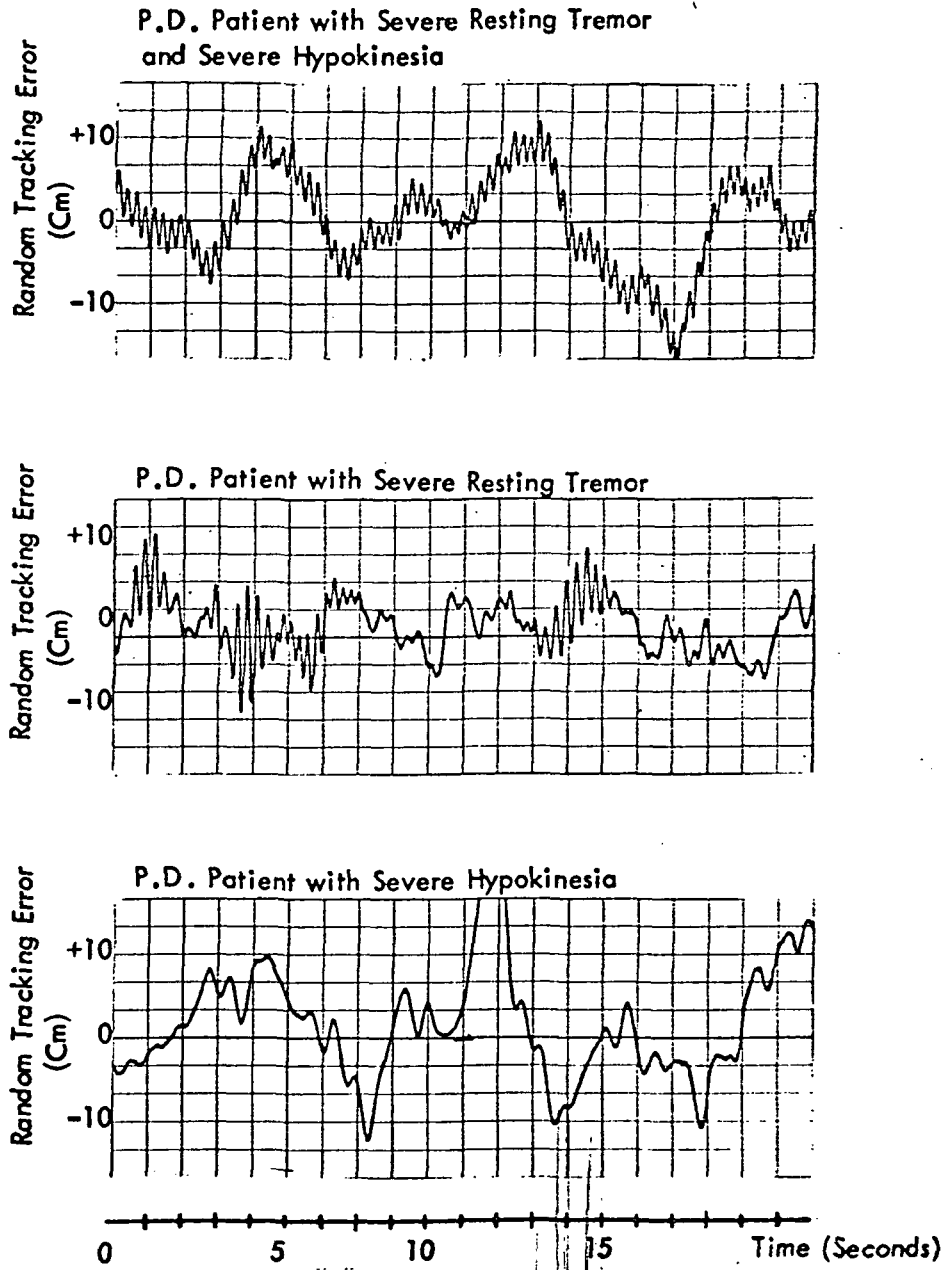mechanical properties of the body part. The present experiments support these latter findings. Very definite reductions in upper limb tremor frequency were noted for the patients tracking with the large position stick. The observed frequencies occurring during purposeful movement ranged between 2.0 and 5.0 hertz while the normal, unloaded range is typically 4.0 to 7.0 hertz. Thus, while the mechnical properties of a limb may not be the only influence on the frequency of tremor they, nevertheless, contribute an important element to it.

Although only a small sample of all the patients and control subjects tested have been analyzed using power density spectra, there do appear to be particular spectral patterns which characterize different groups of individuals. Normal subjects seem to have a much flatter spectrum than the other groups indicating they used a combination of slow, smooth movements and quick, corrective ones. Parkinsonian patients with severe hypokinesia showed much less power at higher frequencies relative to lower frequencies than did the normal subjects. In fact, the slope of the power spectral density curve appears to be a good measure of hypokinesia. The greater the slope is, the more severe is the disorder. Patients with tremulous movements can be identified by the presence of peaks at discrete frequencies in the spectral records.

CHAPTER VII

SUMMARY AND SUGGESTIONS

Summary

The development of highly successful therapeutic methods for the treatment of neurological disorders and the expansion of experimental investigation in neurology and neuropharmacology have led to increasing use of objective methods in such research. Clinical investigators are becoming more exacting in their attempts to detect small changes in neurological function, and it is important that new methodologies for measuring human performance be thoroughly investigated. While considerable reliance is still placed on subjective clinical evidence, more and more attention is being devoted to the development of standardized quantitative performance indices. In the present research, a number of tracking tasks that have proven useful to control engineers and psychologists measuring skilled performance have been evaluated for use in a clinical environment. Three basic tasks have been investigated; namely, step tracking, random tracking, and the Critical Task. The standard quantitative performance measures, reaction time and movement time, integrated absolute error, and estimated effective time delay, were used. More sophisticated phase plane and power spectral analyses were performed on a small sample of the tracking records.

Most tracking investigations have been concerned with situations of a stationary nature, that is, where the task variables are constant and the subject's response characteristics, because of training, have low

variability. In a clinical environment, however, extensive training time is a luxury that simply cannot be afforded. Reasonable stationarity and repeatability are still required if the tracking measures are to be meaningful. In order to minimize variability under these conditions, the four engineering task variables, forcing function characteristics, display characteristics, control stick dynamics, and plant dynamics were kept as simple as possible in the present experiments.

Whenever new quantitative tests for measuring neurologic disorders are developed it is of interest to examine the performance of normal subjects as well as patients on the tests. The tracking test battery was administered to a group of young adult normals, ages 18 to 21, and to a group of older adult normals, ages 50 to 74, for the purpose of obtaining quantitative standards against which patient performance could be compared and to assess the importance of age, sex, learning, and hand dominance on performance. Ten of the older normals were used in a test-retest study to determine reliability measures for the tracking battery. Five of the six performance indices had reliability coefficients significantly different from zero at or above the 5% level. Integrated absolute error and estimated effective time delay had coefficients above .90. Learning effects, measured with the same 10 subjects, were not statistically significant.

Significant differences in performance due to age were found for the step reaction time and step movement time measures. Twenty young adult normals and 15 older normals were used for comparison. The especially large difference in movement time performance was attributed to a more

cautious approach taken by the older subjects. While in general, males tended to perform better than females, statistically significant differences were observed only for the movement time measures in the young normal control group. These results appear to be due to large differences in strength between the males and females. No differential effects for right versus left handed performance were noted in a sub-group of 8 young normals.

A factor analysis of the new tracking measures and established measures from the CQNE and SADLE was performed to provide a perspective on the new tests. The analysis demonstrated that the tracking measures chosen for study were comprehensive in that each of them loaded heavily on a different factor or trait. In addition, integrated absolute error was found to measure a factor identified as Rate Control which was previously lacking in the CQNE. High loadings on the factor Control Precision by both the Critical Task and the rotary pursuit task suggest that the Critical Task, with its added advantages, might be considered as a replacement for the earlier test. As an evaluation of practical utility the tracking test battery was used in a drug trial designed to compare the efficacy of amantadine versus placebo in treating 28 parkinsonian patients already receiving optimal doses of L-DOPA. The selected tracking measures provided information that was useful in detecting and documenting modest but statistically significant changes in motor performance. The findings were verified by comparison with more established qualitative and quantitative measures of performance,

including the professional opinion of two neurologists recorded during
the clinical trial. Taken together, the results of the factor analysis
and the controlled clinical trial offer strong evidence supporting the
construct and concurrent validity of the quantitative tracking measures.

Phase plane diagrams and power spectral density functions were
found to provide a useful means of characterizing the tracking performance
of patients with movement disorders. Both techniques offer a compact
way of describing tracking behavior while still retaining the important
features of the actual movement patterns involved. The phase plane
method, in particular, appears to offer much promise for objectively
evaluating intention tremor. Comparisons of phase plane diagrams and
the neurologist's ratings of 6 multiple sclerosis patients with varying
degrees of intention tremor demonstrated that the phase plane character-
istics are in close agreement with what the neurologist can see.

Suggestions for Future Work

This research effort has shown that tracking can be a sensitive
and convenient task for use in clinical evaluations. Methods for scoring
range from very simple paper and pencil measurements to very elaborate
mathematical treatments. By changes of target speed and other variables,
the task can be made extremely easy or impossibly difficult. The force,
extent, and timing of the subject's movements can be made to cover a wide
range of patterns. As Seashore (1951) has noted, the pattern of
movements involved in a given task is likely to be the most important
factor underlying individual differences in motor skills for normal
subjects, rather than the sense modality or the specific musculature

employed. Thus, once set up, a tracking apparatus can be used to provide a wide range of testing situations, each providing additional information relevant to the subject's ability structure.

While the present selection of quantitative tracking indices has proven reliable and valid, additional research on task variables and performance indices for clinical applications is necessary. Improvements in the present tracking task battery can certainly be made. The random tracking task is an example. The results of the factor analysis indicate that random tracking error measures a trait that should be included in a comprehensive evaluation of motor function. Of all the measures in the tracking test battery, this measure showed the lowest percent of normal function for the parkinsonian patients; and yet, integrated absolute error failed to discriminate between young adult normals and older normals. In the controlled clinical trial, the L-DOPA + amantadine treatment group showed an 11% improvement in this measure over the L-DOPA + placebo treatment group; but this improvement was not of statistical significance because of the large variability in scores.

These results point out the difficulties in designing a random tracking task for use with patients having movement disorders. The target can be made extremely easy or impossibly difficult to follow. Patients are already working under a great deal of stress from their pathological condition, and their margin for test cooperation is markedly reduced from normal. They may thus become easily annoyed or depressed if the test situation is too difficult. The random tracking task requires substantial subject attention and cooperation; and if it is too difficult

for the patients it will affect their task attitude, and the meaning of

the results will be obscured. Additional research with this task is

called for. Shorter task durations and displaying a target circle whose

diameter is proportional to integrated absolute error for the previous

5 to 10 second period might help to lower the high variability in the

patient's scores.

In the case of patients with neurological disorders, not only the

movement pattern used but the specific musculature involved is an

important factor to consider in designing a task. For this reason,

lower extremity tracking appears to be an especially promising area for

future investigations. Multiple sclerosis patients often have severely

affected lower extremities without any major disability in their upper

extremities. For many patients taking part in the L-DOPA and amantadine

drug trial, the most noticeable improvement occurred in their lower

extremeties. Another area worthy of consideration is eye tracking.

Visual and eye movement control problems are among the first to appear

in many neurological disorders, and more precise measures in these

areas could provide a very sensitive means of evaluating therapeutic

procedures.

The present research effort has been concerned with establishing

the effectiveness of tracking tasks for use in clinical applications.

Primary interest has been in the effects of different neurological

conditions and therapeutic drug treatments on the resulting quantitative

data.

Practical questions regarding reliability and validity have been

considered. While additional research on task variables for clinical

use should be pursued, more theoretical orientations concerned with the

clarification of underlying mechanisms responsible for a given pathological

condition or response to a given drug may also be worthwhile considering.

One method for analyzing random tracking data that appears particularly

promising for this type of research is transfer function* analysis. This

method involves a slight extension and alteration of the power spectral

density approach described in Chapter VI and Appendix D. In recent years,

research with transfer functions, which measure the input-output behavior

of a system, has been directed toward obtaining accurate measures of the

diverse functions carried out by subsystems of the nervous system.

Admittedly, only rather crude and speculative identifications of the

anatomical subsystems involved in tracking performance can be made.

However, these identifications do offer advantages over the use of

more general performance measures such as integrated absolute error.

It is quite likely that the subsystems that can be identified by means

of transfer function analysis will be differentially affected by different

disease states, drugs, or other stressors. For this reason, transfer

characteristics should provide a fruitful approach to the study of

motor disorders.

Post Script

There are many opportunities for collaboration between systems

engineers and medical investigators, but the barrier between engineers

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*For nonlinear systems a similar technique known as describing
function analysis must be used.

and physicians is a formidable one. Perhaps the main challenge is for
the engineer to demonstrate the value of his techniques for use in
medical research and actual medical practice. Medical investigators have
learned that it is useful to study those parts of the brain that deal
with movement as a complete system rather than as isolated components.
There is a growing awareness that the functions that feedback control
systems are designed to perform are in many respects analogous to those
required by humans in many of their everyday tasks. The tracking
apparatus serves as a useful framework for studying and describing man's
sensory-motor abilities in terms of systems engineering concepts.

Quantitative measures of motor function are not meant as replacements
for sound clinical judgment, but they may serve to free the neurologist
from some of the routine aspects of an examination and, more importantly,
supply him with more objective and precise information on a patient's
neurological condition. As De Jong (1958) has noted:

> "No other branch of medicine lends itself so well to the correlation
> of signs and symptoms with disease structure as does neurology,
> but it is only by means of a systematic examination and an
> accurate appraisal that one can elicit and properly interpret
> his findings."

It is hoped that the present tracking research has contributed in a small
way to a more accurate appraisal of neurological function and that it
will help to stimulate more wide-spread use of systems engineering con-
cepts in the study of neurological disorders.

APPENDIX A

BRIEF DESCRIPTIONS OF VISUAL ACTUITY AND SELECTED UPPER
EXTREMITY TESTS IN THE CQNE AND SADLE*

CQNE Tests

Vision: Distance vision is measured using a Snellen chart placed 20 feet away from the subject. The subject covers one eye at a time and attempts to read the smallest line possible. The smallest line read completely correct is recorded and the measure used is percent control visual efficiency.

Grip Strength: A Jamar hand dynamometer is used to measure grip strength. Five trials are performed in succession with each trial consisting of the subject squeezing the handle with as much force as possible for 5 seconds. Grip strength is measured using the average of the maximum force exerted for the first 2 trials. Grip strength fatigue is measured as 100 times the ratio of the maximum force on the 5th trial divided by the maximum force on the 1st trial.

Wrist and Shoulder Strength: Wrist and shoulder strength are measured using a modified Newman myometer applied at a fixed point on the subject's hand or wrist perpendicular to the direction of motion. For wrist strength the subject places his arm on the arm rest of a chair with the wrist maximally dorsiflexed. The experimenter applies force

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*More detailed descriptions are found in Potvin (1971).

over the third metacarpal perpendicular to the dorsum of the hand. For

shoulder strength, the subject is seated with his arm extended and held

sideways at a right angle to the body. Force is applied downward on the

wrist. In both tests the subject is told to maximally resist the force.

Two trials are performed without rest with the average of the maximum

force taken as the measure of strength.

Force Steadiness: These tests are basically constant force tracking

tasks requiring the subject to apply a constant 300 gm force to a force

stick. A meter is used to display to the subject his deviation from

300 gm. The test is performed with the arm both supported and unsupported.

Three 10 second trials are conducted for both conditions. The average

of the subject's absolute error for the 3 trials, given in gram second/

second, is used as the test measure.

Tremor: Measures of resting and sustention tremor are obtained

using an accelerometer placed on the index finger of the dominant hand.

For resting tremor, the subject places his arm on the arm rest of a

chair with his wrist hanging relaxed over the edge. For sustention

tremor, the subject extends his arm in front of him at right angles to

the body with the wrist and fingers extended horizontally. In each test,

3 trials are conducted with the average score for the trials, expressed

in G second/second, being used as the test measure.

Reaction Time: The subject's simple reaction time is measured with

a device using a visual and auditory stimulus simultaneously. The res-

ponse required is to remove the index finger from a release button as

fast as possible after the presentation of the stimuli. The average time between stimulus onset and response for 10 trials is taken as the test measure.

Hand Speed and Coordination: A hand tapping board consisting of a row of keys mounted over a set of microswitches is the basic instrument for these two tests. For the hand speed test, the subject is instructed to tap anyone of the keys as quickly as possible for a 30 second period using the index finger. The measure for hand speed is the number of taps registered during the first 10 seconds. Hand speed fatigue is expressed as 100 times the number of taps in the last 10 seconds divided by the number of taps in the first 10 seconds. For hand coordination, the subject is instructed to alternately tap as fast as possible 2 target keys, whose centers are 16 inches apart, without making any errors. The trial again lasts 30 seconds. Hand coordination and hand coordination fatigue are measured in the same manner as the hand speed measures.

Rotary Pursuit: A Lafayette rotary pursuit apparatus which con- sists of a hinged stylus and a 3/4 inch diameter target rotating on an 8 inch disk is used in this test. The subject attempts to keep the tip of the stylus on the target while it rotates at 30 revolutions per minute. The average percent of time on target for three 20 second trials is used as the test measure.

Purdue Pegboard: This task requires the subject to pick up, move, and place, one at a time, a series of small pegs into a prescribed row of holes. The number of pegs placed in a 30 second trial is used as the test measure.

Pencil Rotation: This task requires the subject to rotate an 8 inch pencil using only the thumb, index, and middle fingers. The top of the pencil is rotated away from the body and each time the pencil reaches the vertical position it is tapped on the surface of a table. The subject is instructed to rotate and tap as fast as possible without dropping the pencil. The average number of taps over two 10 second trials is used as the test measure.

Touch Sense: A Cochet and Bonnet monofilament aesthesiometer consisting of an adjustable nylon filament is used in this test. A 1 inch stroke is applied to the dorsum of the hand causing modest bending of the filament. The longest length of filament (in centimeters) for which the subject can feel three of three strokes with his eyes closed is used as the test measure.

Vibration Sense: An electrical vibrator, or biosthesiometer, is applied to the pad of the subject's index finger. With eyes closed, the subject is asked to report when he first perceives the vibratory stimulus. The stimulus is slowly incremented from an amplitude of zero, and the average of three trials expressed in microns is used as the test measure.

Position Sense: This test measures the subject's ability to identify the position of his joints with his eyes closed. The distal joint of the index finger is examined first. Four trials are used. If the subject correctly identifies the nature of the examiner's passive positioning on all 4 trials, the testing is complete and a score of 1 is received.

If not, the examiner goes on to the proximal joint of the index finger

and then to the wrist, elbow, and shoulder, as needed, until the subject

responds correctly to all four trials. If the subject fails to respond

correctly on the shoulder joint a score of 6 is recorded. Integer scores

between 1 and 6 are possible with this scheme.

Two-Point Discrimination: A Sweet two-point compass is used to

apply the stimulus to the subject's index finger. The smallest distance

in millimeters that the subject recognizes correctly as two points on

3 consecutive trials is taken as the test measure.

SADLE Tests

With the exception of Putting on a Shirt, the subject begins each

test sitting in front of a table with his hands flexed and placed against

the edge of the table. The subject is instructed to complete the task

as rapidly as possible. Timing begins with the word "go" and continues

until the test is completed. Each test is repeated twice and measured

to the nearest 0.1 second. The test score is the average of the 2 trials.

Putting on a Shirt: The subject is seated on the edge of a chair

and is handed a man's long sleeve shirt (cuffs unbuttoned) with the

front facing him. His instructions are at the word "go" to take the

shirt, put his right arm through the right sleeve, bring the shirt to

the top of his right shoulder, reach behind his back, place his left

arm through the left sleeve, bring the shirt over his left shoulder,

straighten the collar, and bring the front of the shirt together.

Managing Buttons: A cloth covered board with a 1 inch button

and a buttonhole and a similar board with a 1/2 inch button and buttonhole

are used in these tasks. The tasks are referred to as large and small

button, respectively. The subject is required to unbutton and then

button the cloth as quickly as possible.

Zipping a Garment: A cloth covered board with a 7 inch zipper is

placed in front of the subject who is instructed to open and close the

zipper twice as quickly as possible.

Tying a Bow: A board with two 16 inch laces secured in the center

is placed in front of the subject with the laces placed in parallel

1 inch apart. The subject's task is to pick up the laces, tie a single

knot and then a bow.

Cutting with a Knife: A 7 inch plate, held in place by a suction

device, is placed in front of the subject. A piece of permoplast, 3

inches x 3 inches x 3/8 inches, is placed in the center of the plate

with a knife placed to the right of the plate and a fork to the left.

The subject's task is to pick up the knife and fork, position them for

cutting, cut 2 bite-size pieces of permoplast, and place the utensils

on the plate.

Using a Fork: A 7 inch plate with a 1/2 inch cube of permoplast is

placed in front of the subject. A fork is placed to the left of the

plate. The subject picks up the fork, spears the permoplast, and

brings it up to his mouth.

Squeezing Toothpaste: A board with a 1/2 inch line drawn in the center and with an uncapped tube of toothpaste on the right is placed in front of the subject. The subject picks up the tube of toothpaste, squeezes it onto the line, and puts the tube back on the table.

Dialing a Telephone: A standard, spring loaded telephone is placed directly in front of the subject. Without lifting the receiver, the subject dials 764-7172 which is written on a card in 3/8 inch letters placed in front of the telephone.

Manipulating Safety Pins: Two standard 1 1/2 inch safety pins, one opened and one closed, are placed in front of the subject. The task is to pick up and close the first pin and then pick up and open the second.

Putting on Gloves: A pair of garden gloves are placed in front of the subject whose task is to put on both gloves and clasp his hands together with his fingers intertwined.

APPENDIX B

INSTRUCTIONS READ TO SUBJECTS BEFORE
ADMINISTRATION OF TRACKING TEST BATTERY

"Please be seated. Place your right arm on the control stick, grasping the handle so that your upper arm is vertical. Make yourself comfortable and remain in this position during the tests.

"You are about to take part in a tracking test examination that measures different aspects of your ability to coordinate your eyes and hand. (Experimenter turns up scope intensity) You now see two vertical lines near the center of the screen. The large vertical line is now stationary. The position of the small vertical line is controlled by movements of the control stick. In general, if you want the small line to move to the left you must move the control stick to the left; and if you want the line to move to the right, move the control stick to the right. Your task in this set of tests will be either to match the movement of the large target line or to compensate for movements of the small line away from the large line."

Familiarization Procedure

"Your first task is to test the control stick action and "feel" by simply moving the stick back and forth at a steady rate. Keep the small line within the limits of the screen, but don't worry about being exact. Just move free and easy. The trial will last for one minute.

"Your next task is to move the control stick back and forth as rapidly as possible again keeping the small line within the limits of

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the screen. I will tell you when to start and stop. The trial will

last for 20 seconds.

"Now that you have become somewhat familiar with the characteristics

of the control stick, we are ready to begin the tests."

Step Tracking

"As we start the first test the large vertical line or target will

move to the right of the screen. Position the control stick so that the

small vertical line or follower lines up with the target. When we begin

the test the target will jump suddenly to the left and then to the right

and so forth at approximately 5 second intervals. Your task is to follow

the target with the follower by proper movement of the control stick.

Make your movements as fast and accurate as possible after the target

makes its jump. Hold the stick steady until the next jump. Do not worry

if you overshoot the target and have to move the stick back. You will

be scored on how fast you react to target movements as well as how fast

you perform your movements. Each trial will consist of 6 jumps. There

will be 5 trials with a rest in between. Any questions?"

Random Tracking

"In this test the large target line will remain fixed in the center

of the screen. You should begin by having the control stick in the center

position. When the test begins the small vertical line will start moving

back and forth across the screen in a random manner. You must then

begin moving the control stick to keep the small line as near to the

center of the screen as possible. That is, you must compensate for its

movements. The task is much like driving a small sports car down a winding road under conditions of poor visability such as fog. Your score will depend on the average deviation of the follower from the center. There will be five 75 second trials. Any questions?"

Critical Tracking

"In this test the target also remains in the center and you should begin by having the control stick in the center. When the test begins the small follower line will begin moving off the screen in one direction or the other. You must again compensate by moving the control stick to keep the line in the center. In this test, however, the line will respond more sluggishly to your movements than before so you must make your movements more quickly. As time increases it will become more difficult to keep the line in the center. The more you allow the line to stray from center, the harder it will be to control. This test is analogous to driving a truck without brakes down a hill with the speed gradually increasing as you go. The test ends when you can no longer keep the truck from going off the road into the ditch. Your score depends on how long you keep the line on the screen. There will be 20 trials with a short rest between each 5 trials. Any questions?"

APPENDIX C

INSTRUMENTATION

The apparatus used in the tracking studies consisted of the following parts:

I. Function generators

    A. Series of timer-relays for generating rectangular pulses for step trakcing (Figure C.1)

    B. Pseudo-random binary noise generator and analog filters for random tracking input (Figures C.2 and C.3)

II. Computing equipment

    A. Twenty-four amplifier AD-1 analog computer

        1. To prepare function generator signals for display

        2. To compute performance measures

        3. To simulate controlled element dynamics

    B. Logic circuitry

        1. To properly time different aspects of tracking tasks

        2. To control critical task (Figure C.4)

III. Display equipment

    A. Subject oriented: Dumont 737A Large Screen Indicator and special circuitry to split beam into target and follower signals (Figure C.5)

    B. Experimenter oriented

        1. Digital voltmeter to display performance scores

2. Brush recorder to display time tracings

3. Mosley x-y plotter to display phase plane trajectories

IV. Position control stick designed and constructed by the University of Michigan Man-Machine Systems Laboratory

V. Four channel Ampex SP-300 FM recorder to obtain permanent tracking records

The low frequency random voltage used as a target signal in the random tracking task was obtained from a 12 stage sequence generator followed by a low-pass analog filter (Figure C.2). The sequence generator is a clock driven shift register with the modulo-two sum of the twelvth, sixth, fourth, and first stages fed back to the first stage. With this feedback, the output is a pesudo-random sequence of period 2^{N-1}, where N is the number of stages, in this case, 12. This can be shown to be the period which can be obtained using an N stage register. The sequence is then low-pass filtered to provide analog noise with closely controlled characteristics.

The clock frequency chosen is a function of the cutoff frequency of the low-pass filter. The clock frequency must be high compared to the cutoff frequency to ensure that the analog noise has a flat spectrum out to the bandwidth of the filter. However, too high of a clock frequency will result in a skewed analog noise amplitude distribution (Gilson, 1966). It has been found that a clock frequency to cutoff frequency ratio of about 20 to 1 yields an analog signal with a closely approximated Gaussian amplitude distribution. For the cutoff frequency of 0.3 rad per

second that was used in this set of experiments, a clock frequency of
1.5 hz was used. This yields a ratio of 30 which is sufficiently close
to the optimum ratio to produce satisfactory results.
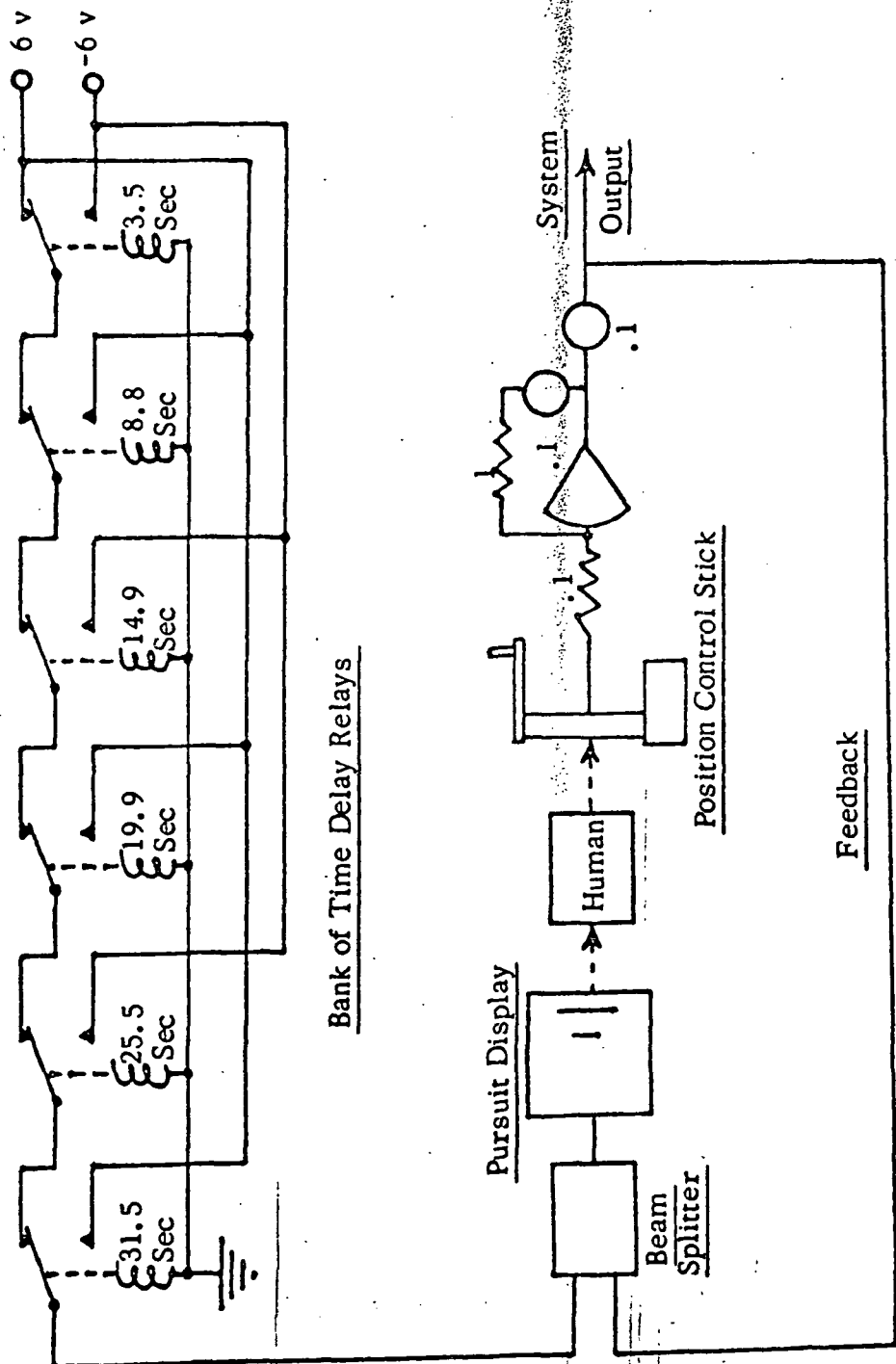
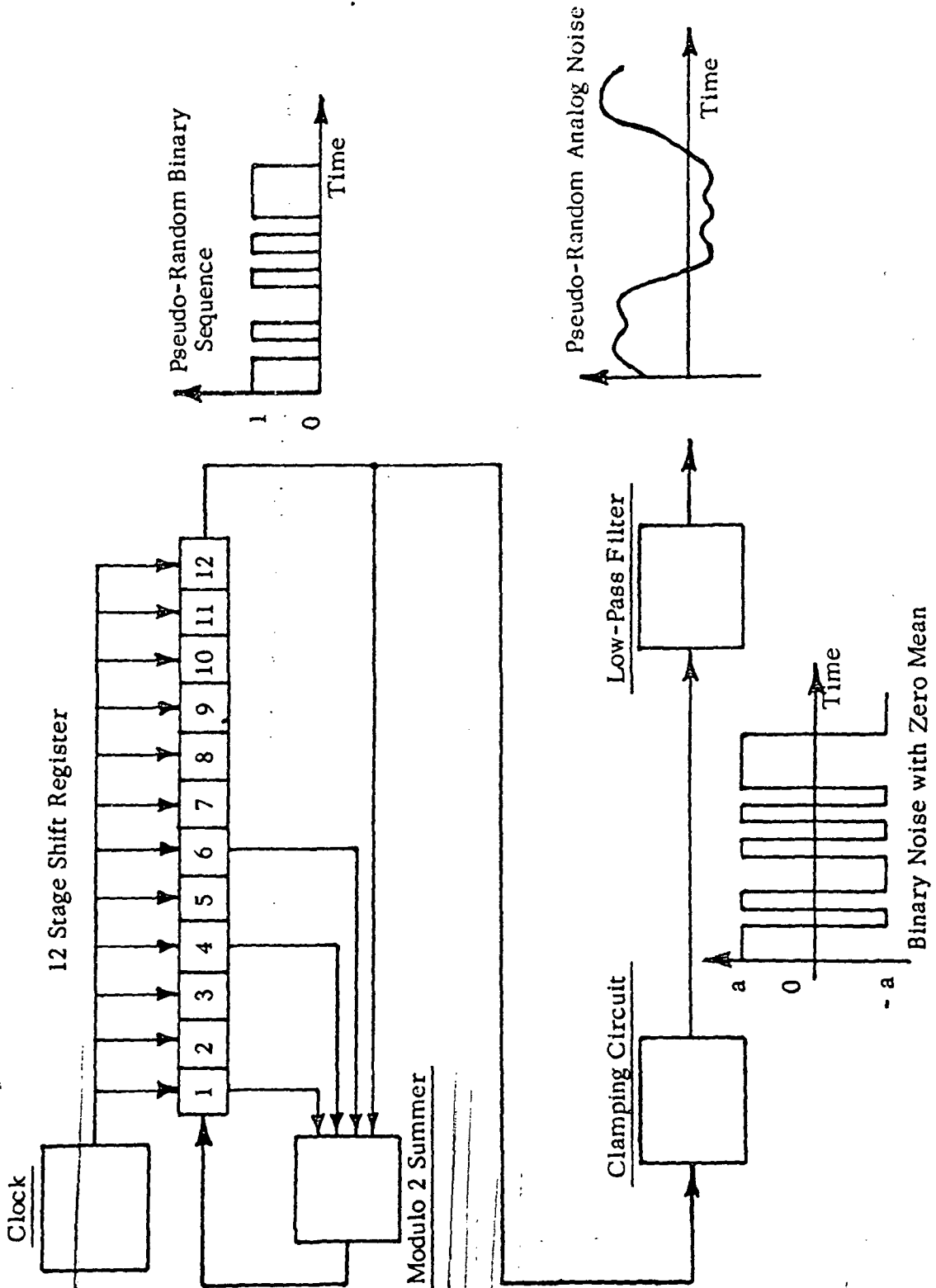Fig. C.1 Computer Mechanization for Step Tracking Task

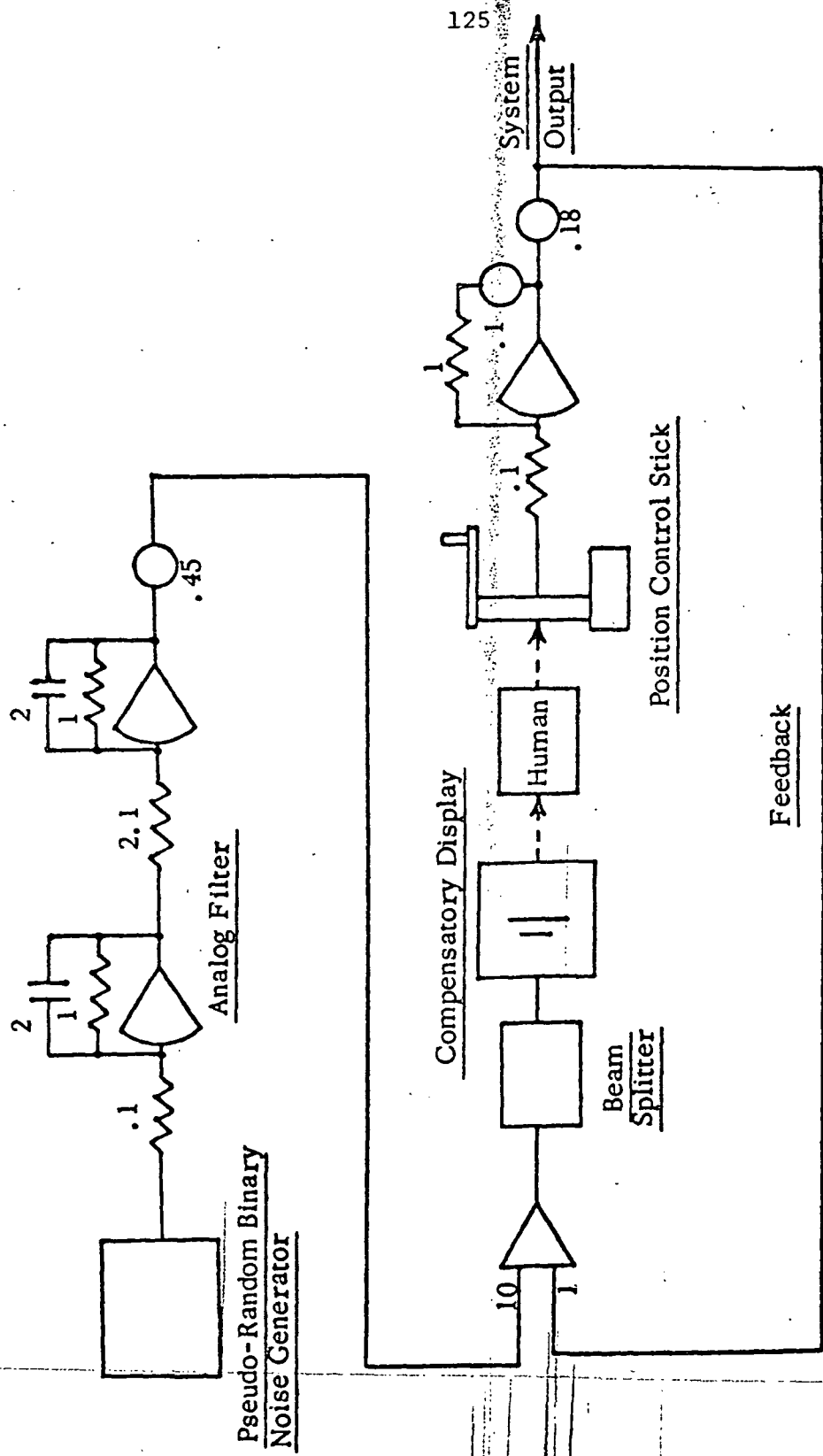Fig. C.2 Pseudo-Random Noise Generator.

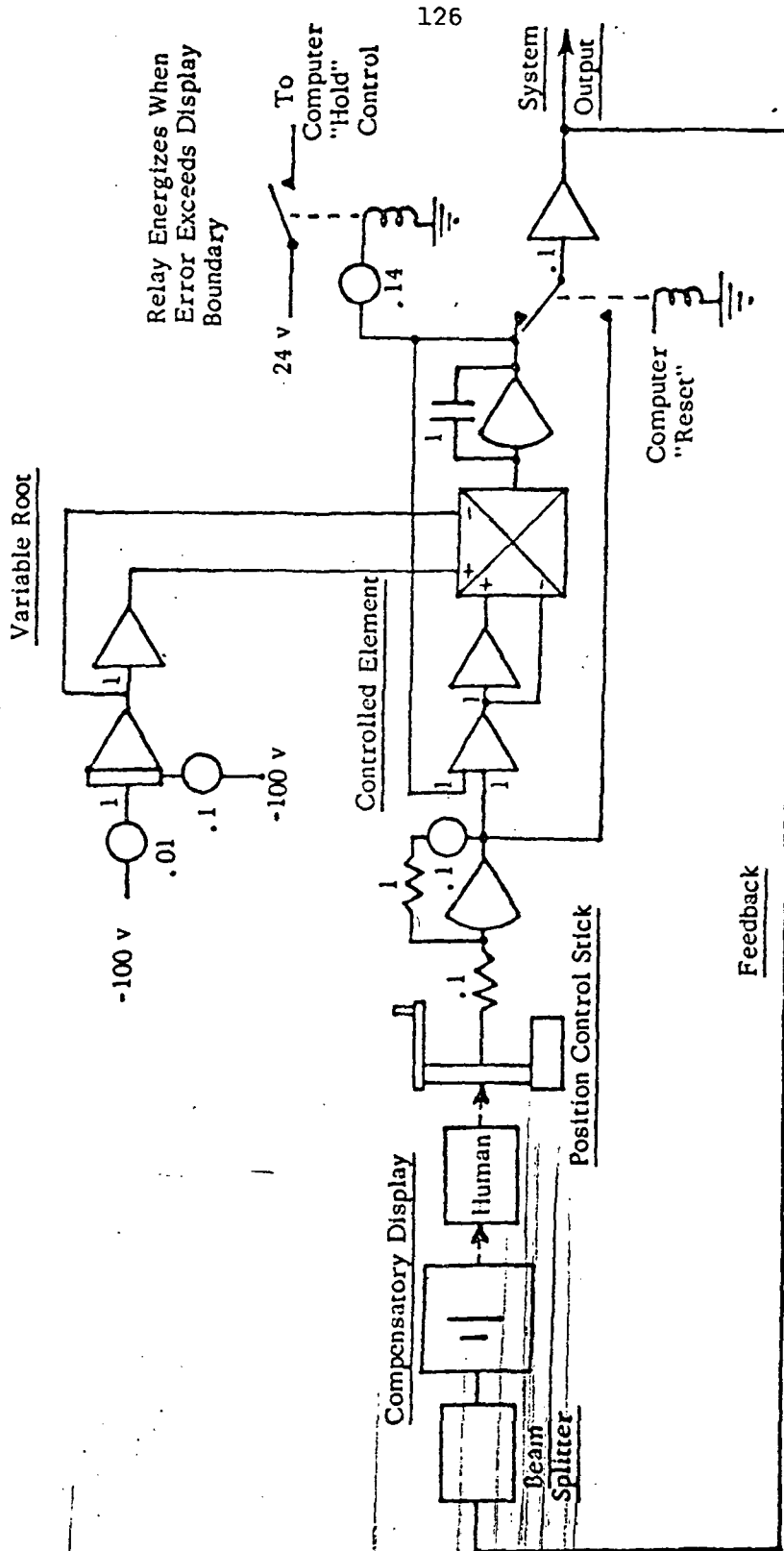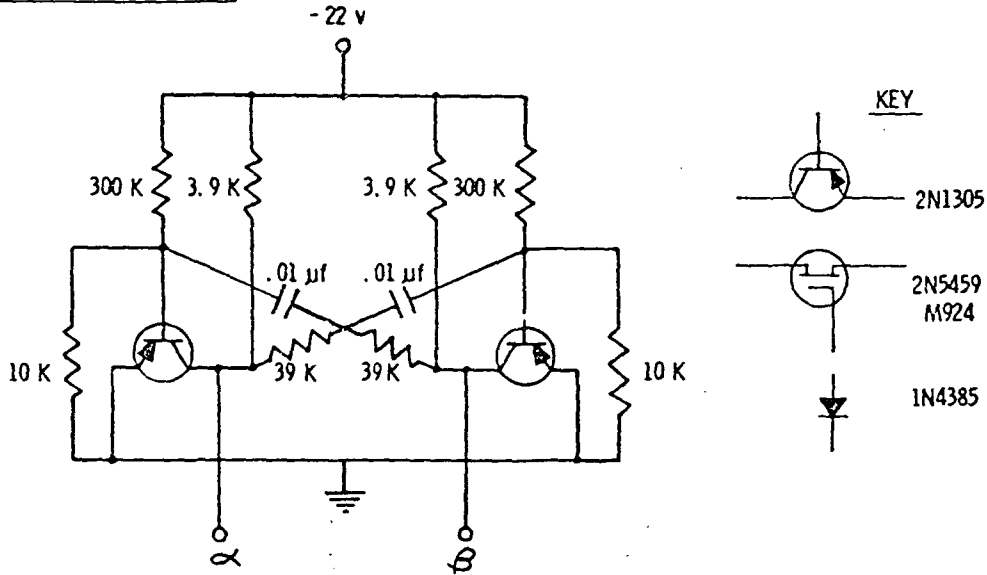Fig. C.3.   Computer Mechanization for Random Tracking Task

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Fig. C.4 Computer Mechanization for Critical Task

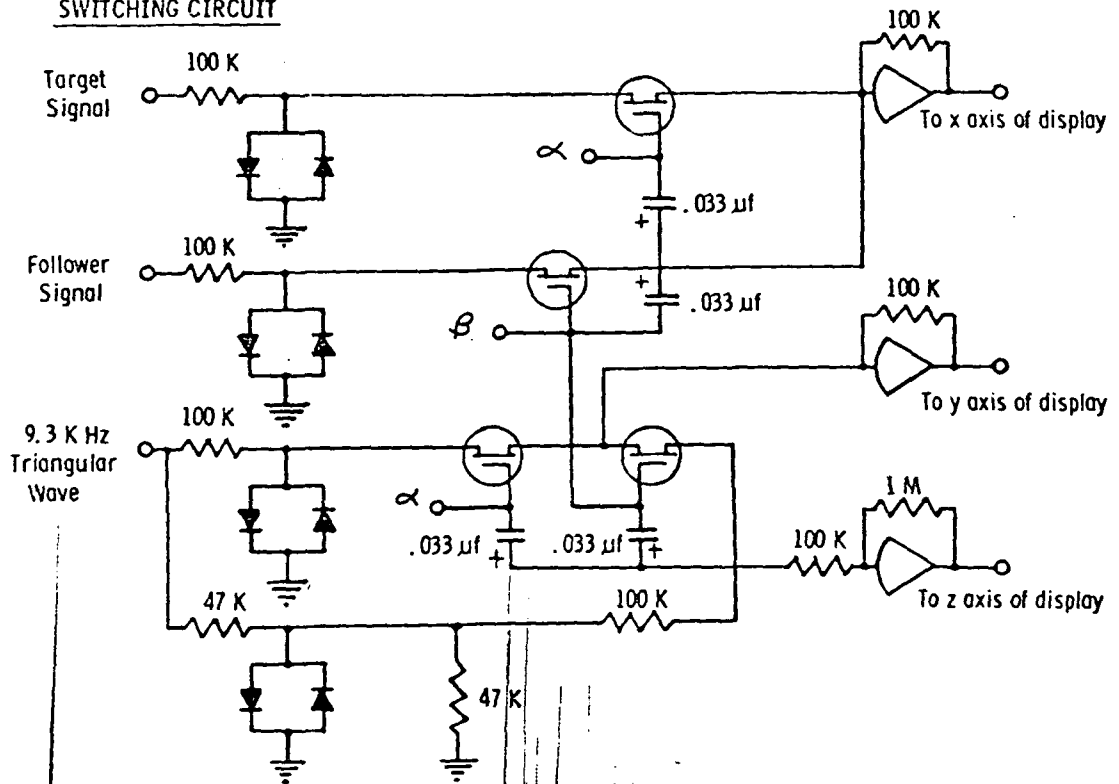OSCILLATOR CIRCUIT

SWITCHING CIRCUIT

Fig. C.5 Beam Splitter Circuitry

APPENDIX D

TECHNIQUE FOR OBTAINING POWER SPECTRAL DENSITIES

Error power spectral density functions were obtained from a computer analysis of the error records for the random tracking task. The analysis makes use of programs written by Stern (1971).

As implemented, the technique involves calculation of the error autocorrelation function and subsequent computation of its Fourier transform to obtain the error power spectral density function (Figure D.1). The autocorrelation function is defined as:

$$R_{ee}(T) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} e(t)e(t - T)dt.$$

In practice, it is possible to correlate only over a finite time span and thus obtain only an estimate of the true function. For this purpose, an on-line continuous correlation program for a Hewlett-Packard 2115A mini-computer was employed. The error signal was sampled at 20 times per second and correlation functions were processed in blocks of 256 samples. Each newly calculated correlation function was averaged with the previous estimate to obtain the current average estimate. The error records consisted of five 75 second runs, and the final correlation estimate was based on the average of 25 blocks of 256 sample each.

The error power spectral densitites were obtained by Fourier transforming $R_{ee}(T)$ as shown in the following relationship:

$$S_{ee}(f) = \int_{-\infty}^{\infty} R_{ee}(T) \, e^{-j2\pi ft} \, dt.$$
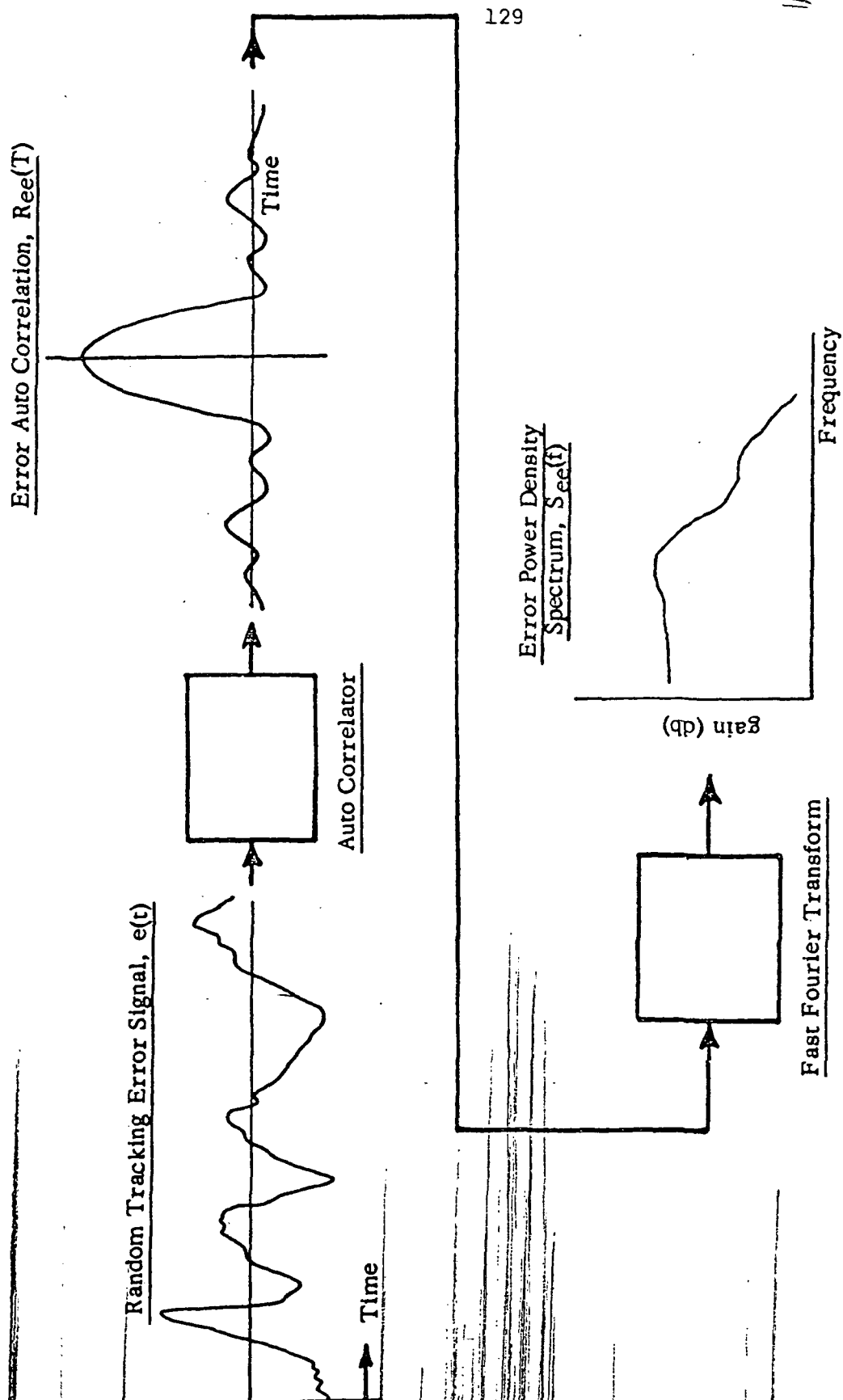
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Fig. D.1 Calculation of Power Spectral Density Functions.

A 256 point Fast Fourier Transform based on the algorithm developed by Cooley and Tukey (1965) was used for the integration process. Since (auto) power spectral density functions have a zero phase angle for all frequencies, only the magnitude of $S_{ee}(f)$ was considered.

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