WORKER PROFILE:
LEARNING PATTERNS FOR MOTOR TASKS

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(ABSTRACT)

This research demonstrates the feasibility of modifying a Predetermined Time Standard (PTS) to model a specific worker precisely and efficiently. The Worker Profile uses the results of a half hour of testing to algebraically modify each of the work elements in the PTS. The modified system can then be used with any job that has been described in the PTS. Specific performance times can be estimated for the modeled individual on each of the described jobs.

The traditional functional assessment techniques developed by medical, psychological and social care providers lack the quantitative precision of industrial engineering work descriptors. In addition to providing the rehabilitation engineer a usable assessment of the client's abilities the Worker Profile should aid in the sharing of information among the specialists on the rehabilitation team.

Unlike previous efforts directed at modeling disabled workers' abilities, this study individually modifies the elements used to describe unique, specific jobs. The element by element Worker Profile approach encourages proper job selection and work station modification. The model produces a Worker Profile which can be used to predict the worker's per-

formance on any job for which an appropriate job standard has been written.

The Worker Profile Model offers the employer of assembly workers an opportunity to predict the performance of disabled workers on specific jobs without the expense and time required to train and test them on each available job. The model has several additional qualities including reduced assessment costs and extremely flexible application both in the performance of existing jobs and to the modification of jobs to optimize them to the disabled workers' abilities.

In addition to extending the Worker Profile Model this study examined the effect of practice on the work behaviors of disabled workers. Practice has been observed to affect differentially the speed and accuracy of work elements among able-bodied workers. The effects of practice were previously undocumented for disabled workers. Examination of work element performance changes as learning occurred not only identified the locus of improvement in job performance, but also, illustrated a qualitative difference in learning patterns when a tactical improvement in work method occured.

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My father taught me the meaning of work. My mother taught me about starting things. My wife taught me the value of finishing things. And, my committee held the carrot and stick. For all their inspiration, support, and patience, I am grateful.

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INTRODUCTION

Rehabilitation of the physically disabled has been developing along certain identifiable lines for the last one hundred and fifty years. The earliest systematic effort at rehabilitation is generally attributed to Dr. Howe who established the Perkin's School for the Blind in Boston in 1837 (Riggor and Lorenz, 1985). For the next eighty years rehabilitation was primarily the domain of physicians, clergy and social workers (Frey, 1984). In this period one worker, often a nurse or teacher, worked with one client. The goal was simply to enable the client to cope with life. Success was equated with survival. Much of the vocabulary and many of the procedures still used today come from this period of rehabilitation development.

In the 1920's functional assessment began to come into common use to determine the extent of loss due to accident, primarily for legal use in workers compensation decisions (Frey, 1984). In the 1940's the assessment of disability shifted focus to assist the rehabilitation counselor in mainstreaming the handicapped. The primary tool of the rehabilitationist became the work sample.

A work sample is time consuming to conduct, must be repeated as learning takes place to determine behavioral changes, and has little transfer value to other work situations. Failure of an individual at a work sample may have many causes and, other than the tester's subjective opinion as to the client's potential, tells very little about the client's chances of success on other similar jobs.

In the 1960's, as government money came to play a major role in rehabilitation, functional assessment became an accountability tool for measuring the bureaucracy's effectiveness. Current trends in functional assessment are making the system more accountable to both the disabled and the sponsoring organization and opening lines of communication between the various members of the rehabilitation team. Current efforts are making work analysis more elemental to quantify and standardize reports.

Functional assessment in the past has been oriented either toward the medical practitioner or the social worker (Agre, 1984). The traditional clinical approach to assessment is based either on the physical analysis of affected tissues and organs or is couched in gross structural terms that provide only a qualitative description of capabilities. The medical microstructure descriptors do not translate well into work motions. The medical qualitative diagnoses may rule out some work environments but do little to assist the industrial engineer in determining what the client can do, nor do they offer much assistance in modifying the work environment to maximize the worker's efficiency on the job. Alternatively the social workers and counselors have used macromotion descriptors referring to the client's ability to interact with the environment.

The social worker's traditional assessment tool is the work sample. The work sample is a series of tasks typically performed in the course of a specific job. A work sample for a hotel maid's job might consist of stripping a bed, making-up a bed and vacuuming a carpet. A food services work sample could include setting a table, bussing the table and washing dishes. Because of work samples originated in other disciplines, none of these methods seems to be totally appropriate to the vocational area.

In the 1940's rehabilitation began moving toward generalizeable quantified measurements. No longer would one therapist work with one client, starting from scratch with each new treatment. Polio researchers found that classes of clients could be similarly described, and report terminology shifted from the medical jargon previously used to measures of percent normal and rankings on common scales (Agre, 1984). The Functional Assessment Inventory (FAI) was developed to quantify further assessment measures in client files (Crewe and Turner, 1984). This analysis allowed professional specialists to communicate and share findings. Although the FAI was a major advance over previous assessment techniques, it was still very general and more of a qualitative evaluation of the work environment than a measure of job skills. The Life Functioning Index (LFI) was developed to measure degree of self care (Crewe and Turner, 1984). This LFI measured general employability rather than the client's probability of success on a specific job. One of the most significant advances over previous systems was the LFI's standardization; it reduced tester training and removed subjective evaluation (Halpern and Fuhrer, 1984). Although a movement was gaining momentum to generate quantitative testing with results that would extend to many future situations the social science and medical background of the field limited the success of attempts at the generalized measurement of vocational potential of the client.

Industrial engineers have used worker modeling for many years to design jobs (Karga and Bayha, 1977). Predetermined time systems (PTS) are among the most effective and efficient methods of modeling work. PTS are sets of work elements that can be arranged in sequences to completely describe a wide range of jobs. Each work element is assumed to have a cost (either in terms of energy or time expended to perform) and the total cost of a task is assumed to approximate the sum of the costs of the individual elements. The technique allows industrial engineers to develop optimal methods for task performance (i.e., to minimize energy or time expended on the task) and to estimate performance times for assembly line balancing or for piece work payments. PTS have not been applied to the performance of disabled workers because they are based on the average able-bodied workers' manual abilities.

Problem. There is no simple direct way to modify PTS to account for performance times of the work elements of disabled workers. When a single element is timed in isolation, acceleration and deceleration errors are encountered. Repeated performance of a single element results in unnaturally rapid actions. Frame-by-frame analysis of filmed work sequences is a time consuming and boring effort which is rendered almost worthless because it is difficult to detect visually the transition points between consecutive elements. Also, delays that occur during the performance of one element may be more correctly assigned to another element;

when a reach is slowed while the worker visually selects one object to be grasped, the extra time should be associated with the grasp element for which it is required, not the reach element during which it occurred. And finally, little is known about how disabled workers' performances change with practice.

The alternative to simple repetition or direct observation of work elements used in this dissertation involves the use of multiple complex tests to solve for a set of unknown work element times. Twelve Modapts (Heyde, 1983) like elements are used with individually modified performance times for each worker. In addition to simplify calculating the mean performance time for each of the elements learning effects are also studied.

LITERATURE REVIEW

FUNCTIONAL TESTING AND METHODS ENGINEERING

Hasselqvist (1971) examined available functional assessment tools for rehabilitation engineering. He found Motion Time Methods (MTM) to be of some use in evaluating work, but it fell short of proper assessment of individuals. Work samples were found to offer too conservative a measure of the abilities of the disabled because failure at one subtask could eliminate an entire job from consideration. Simple single motion tests were found not to predict well how the individual would perform on a complex job that required integration of many abilities. Hasselqvist suggested that an intermediate functional test approach would be more useful. "Between these two extremes - tests on complete work cycles and tests on the performance of single basic motions - it is of course possible to construct tests that include complete but short motion sequences." (p. 11)

Given functional motion sequence tests Hasselqvist said that an MTM type analysis would allow frequency distributions to be generated. These work motion frequency distributions could be compared to the individual's demonstrated abilities to match people with the work that they could most easily perform.

Chyatte and Birdsong (1971) compared assessment methods available and used in medical, psychological and social/welfare testing.

Medical/neurological testing measures the client for motor power, agility, perceptual abilities and intellectual functioning. Although some objective measurements were made, they were primarily for comparison with other similar, but not identical, examinations made at other times to detect changes in the individual over time. Deficit assessment by psychologists were made with tests for intelligence, motor performance and perceptual organization. These were found to confound motor and nonmotor factors, and/or only grossly define motor activity. Social workers were using can-do/no-can-do tests comprised of work samples, activities of daily living and vocational tests. While all of the above were felt to have value, none provided detailed information about deficits existing in the subunits of motor performance. Industrial engineering techniques, especially MTM, were suggested as a way of making quantitative evaluations to determine the extent of motor impairment, spontaneous recovery and treatment efficacy.

Mink (1975) proposed a scheme for using industrial engineering methods, especially MTM, to assess the disabled. His approach was to use functional tests and a team of specialists and to generate a percent normal value for each MTM motion. Each functional test would use several MTM motions in sequence to simulate work activities, but these tests would be shorter than the conventional work sample. The basic evaluation team would include the director of the foundation, a training specialist, a workstudy engineer, an industrial engineer and the foreman of the training department. The basic team would have available for consultation psychologists, psychiatrists and physicians.

Brickey (1981) found that most sheltered workshops do not systematically analyze job layout and methods because:

1) The staff employees have social science and education backgrounds and are not familiar with methods engineering analysis and MTM.

2) The staff assumes that retarded workers can neither perform complex tasks nor use training in special methods.

3) Management feels that short term subcontracts do not warrant analysis.

4) Line managers fear that complex systems would cause more down time.

The absence of systematic work methods adds to worker inefficiency, makes the shop less competitive, lowers wages, reduces the contract work available to the shop, and fails in the workshop's mission to train the workers to a level where they can go out into community jobs.

Brickey (1981) conducted an experiment using 20 subjects with I.Q.s between 24 and 57 and no severe impairment of hands or vision to determine whether work analysis and methods training would help retarded workers to be more efficient. Half of the subjects were trained to work according to an engineered standard and the other ten subjects were trained in the normal supervisor demonstration/self determination method. Each subject was trained until capable of performing six errorless assemblies. Significant improvement was demonstrated in the productivity of the group trained to the standard method. No difference in either error rate or training time was found.

AVAILABLE MOTIONS INVENTORY

Dryden, Leslie and Norris (1980) report a joint effort between the College of Engineering, Wichita State University and the Cerebral Palsy Research Foundation of Kansas, Inc. to develop a service delivery system to meet the needs of severely handicapped people. The goal of the program was to create a total lifestyle for the clients including vocational, educational, transportation and independent living. Lack of anthropometric and biomechanical data for the disabled population led to the development of an apparatus called the Available Motions Inventory (AMI). The AMI quantitatively measures the individual's abilities at machine control and assembly tasks.

Dryden et. al. (1980) describe the controls portion of the AMI as an adjustable frame with moveable modules. Each of the controls modules is a one square foot aluminum panel with a number of switches of a single type on it. The controls modules can be positioned horizontally or vertically; they can be high on the frame or low; they can be centered or moved to the client's sides. In addition to the controls tests there is an assembly work station, a simulated drill work station and a series of finger, hand and arm strength and speed measures. Data are collected on the client's abilities with switches (rotary, detent, push button, toggle and slide switches); rate and accuracy of control activation; finger, hand and arm strength, reaction and speed; and on a series of simple assembly task elements.

AMI results show inter-client and intra-client differences useful in job selection and modification. Between client differences are made by direct comparison of results on the individual's tests with the normal standard. Within client differences show areas of relative strength which can be utilized in selecting preferred control type, position and orientation. Of 100 handicapped individuals placed on jobs during system development only one placement and adaptation was reported as unsuccessful.

Malzahn and Kapur (1980) used the AMI to measure industrially relevant residual motor abilities and effectively identify job modification requirements. Design engineers need to know the available resources and required outputs in order to produce a quality solution. Work station design for the disabled worker should be approached as an iterative series of comparisons between task requirements and the manned system's performance. AMI advantages over other assessment methods were:

- Half a day of testing compared to one to two weeks for work samples.
- Wide range of abilities tested.
- Less administrator training.
- Quantitative results evaluated before job compatibility is considered.
- Small building blocks of data can be used to evaluate many different jobs
- Failure at one subtask does not invalidate the entire test.

Although AMI assessment does not automatically redesign jobs, "The tough one-on-one design problem is at least a better defined problem through the use of this ability evaluation system." (Malzahn and Kapur, 1980, p. 118)

AMI AND JOB MODIFICATION

Kapur and Liles (1982) evaluated the AMI as a physical assessment system and developed job design guidelines and techniques to develop one-on-one work place modifications. The chief problem with work place redesign for the physically disabled is assessment, because the disabled differ from the norm and from one another. Using a mixed (able-bodied and disabled) group of workers, Kapur and Liles first gave each a full AMI test series. Then they collected performance data on each at a set of simulated job stations (punch, drill press, telephone switch board, conveyor belt, assembly/disassembly, and quality control tasks). Using data on twenty of the subjects to generate regression models and the other nine for validation, they found good prediction of performance speed but poor prediction of accuracy and quality. Able-bodied subject's performance and two handed job performance were systematically over predicted.

Rahimi and Malzahn (1984) attempted to measure human functional abilities so as to distinguish between individuals and aid in the task design process. Using an AMI Motion Class Standard for jobs, they computed an index of predicted performance as the frequency of a motion for the job multiplied by the z-score for that motion from the individual's AMI test scores. Large negative values for an index indicate that the motion is important to successful completion of the job when performed according to the standard under consideration, and it is not a motion that the client performs well. The job is iteratively modified to remove worst case motion requirements until the size of negative indices is minimized. Final design recommendations based on this procedure were found to be good first approximations from which on-the-job fine tuning could begin.

PREDETERMINED TIME STANDARDS (PTS)

Winkler and McQuaid (1984) report that the AMI assessment has two major shortcomings; the tests are redundant and the motion class output is in a very specialized physiologically oriented terminology. Winkler and McQuaid found that the AMI tests could be described using the MTM Predetermined Time Standard (PTS) and that the standards indicated that the 71 tests were repeatedly measuring the same motions. The redundancy results in a high test cost. They concluded that the use of a PTS could reduce AMI testing costs and produce a more widely usable report form.

Heyde (1983) describes his development of a new PTS called Modapts Plus. After extensive analysis of human activity, Heyde found that able-bodied, unhurried, unencumbered, unexceptional individuals moving at comfortable "natural" speeds make elementary foot motions in 0.429 seconds, finger motions in 0.143 seconds, hand movements in 0.286 seconds, forearm actions in 0.429 seconds, whole arm moves in 0.571 seconds and eye shifts in 0.286 seconds. Upon noting that all of these move times are multiples of 0.143 seconds, he made this his unit of time and called it a work module unit (MOD). Heyde defines a set of Modapts Plus elements by assigning each elementary motion a letter and a number. The number assigned to each element represents the number of Mod units required for an unhurried normal able-bodied individual to perform the simple motion. The letter assigned to each element is a mnemonic to its action. (See Table 1).

Masud, Malzahn, Dinasan and Singleton (1985) report that PTS's are normally considered most appropriate for tasks with cycle times in excess of one minute. A study was conducted to determine if one of these widely accepted and simple to use systems could be used with AMI testing. Using a Modapts standard for a subset of AMI tests, able-bodied subjects were tested. The experiment demonstrated certain problems with the technique. The AMI tests used had cycle times of less than 30 seconds, and the resulting test total times were significantly shorter than the Modapts predicted total times. It was concluded that although PTS'S hold great promise, some adjustment method would be needed before AMI testing with predetermined time standards could be used to predict the probability of success of handicapped clients on specific jobs or to determine disabled worker's efficiency on specific work tasks.

A study was conducted to determine the feasibility of using PTS analysis to improve AMI testing (Masud, Malzahn, Dinasan and Singleton, 1985). Two types of PTS were compared, MTM-2 and Modapts. Both were found to be usable in research on AMI testing of able-bodied subjects although each was found to be biased in that predicted work times were

Table 1. Examples of Modapts elements.

M1 - 0.143 second finger motion (M = Motion)
M2 - 2 mod hand move (finger tip moves less than 2 inches)
M3 - 3 mod forearm motion (finger tips move < 6 inches)
M4 - whole arm moves carrying finger tips < 12 inches)
F3 - Foot move without moving lower leg (F= Foot)
W5 - foot and leg move one step (W = Walk)
E2 - 0.258 second eye fixation (E = Eye)
P0 - simple release at end on arm motion (P = Put)
P2 - Put with feedback (one dimension alignment)
P5 - Put with multiple feedbackS (precise final location)
G0 - touch or contact Get (G = Get)
G1 - simple grasp Get (e.g. pencil on flat surface)
G3 - Get with feedback (e.g. coin from flat surface)
J2 - Juggle in fingers, reorient object (J = Juggle)
X4 - Exert force (e.g. press tack into wall)

longer than were observed times in completing AMI tests. Modapts task time prediction was found to be closer to actual times than MTM-2. The bias was worse in the case of settings and rate tasks than in assembly type tasks. It was assumed that the simple nature of the tests was the cause of this bias. It was concluded that the use of PTS with AMI testing offered many advantages, but some adjustment technique would be needed to make the testing practical.

A Modapts based assessment system was developed by Chris Heyde (1983). This system, Workability, measures a client's capability to work with one or two hands; measures high and low conscious control; ability of the client to judge his own capacity and determination to succeed. Workability is used primarily to position the client along a spectrum of employability ranging from heavy warehousing through assembly to office work. A typical recommendation might suggest that the client be assigned to light assembly work with fine motions restricted to the right hand and not be expected to continue unsupervised for extended periods of time. Workability instructions for client testing are very detailed and allow testing to be performed by testers with little training in the procedure. Workability testers do not need to know Modapts.

TWO WORKER PROFILE MODELS

The primary goal of the Worker Profile modeling effort was to prove the feasibility of mathematically modeling the disabled worker (Ward, 1988). To be of practical value the model needed to be quantitative, economical to apply and generalizeable to a large number of jobs. In the course of this study two models were developed; one was a Motion Class Model similar to the AMI standard model, and the other was an Action Set Model. Each of these two models generates a Worker Profile which can be used to predict worker performance on a large class of light assembly type jobs. The Motion Class Worker Profile has several advantages over previous AMI based predictors, but still requires job descriptions to be written in the AMI motion class system and the collection of parametric data on each job. The Action Set Worker Profile is a purely algebraic model based on actions performed by the individual and uses neither statistical nor physiological data. The use of algebraic methods rather than statistical information reduces the effort needed to generate standards for new or modified jobs. Use of action based standards rather than physiological body motions allows the worker to do whatever is needed to accomplish the action without regard to how an able-bodied person might have performed the same action; this is a norm-independent method.

Each of the two models developed in this research effort uses a Worker Profile to describe the abilities of the disabled worker. As used in this study Worker Profile refers to a vector or N-tuple that uniquely describes an individual. When combined with a job description, the Worker Profile makes it possible for the user to predict the individual worker's performance on the specific job although the worker has never performed the job and indeed may require considerable training to perform it.

In the case of the Motion Class Worker Profile the vector describing the individual consists of 14 Z-scores derived from the AMI test. This 14-tuple is multiplied by a job description vector of the relative importance of each of the 14 motions for the job under consideration.

The Action Set Model uses 12 Modapts-like actions to describe jobs. To make the Action Set Worker Profile norm-independent action times have been completely removed from the action descriptors. All action times are captured in the 12-tuple Action Set Worker Profile. By placing all time related information in the Action Set Worker Profile and computing this vector algebraically no assumptions are made as to how an action is accomplished. Once a Worker Profile for an individual is calculated, this can be used with the standard for any job to predict performance time. This predicted performance time can be compared to the normal expected time for the job to estimate the individual's efficiency on the job. To assess job redesigns the rehabilitation engineer need only rewrite the job standard to avoid actions that the worker has difficulty with and calculate a new [job description] * [Worker Profile] dot product.

Like Brickey (1981) this research used work method instruction. Unlike Brickey this instruction was used during testing rather than on the job. Methods instruction speeded the learning and unlike the situation in conventional AMI testing learning was encouraged before the test; not during the test. By having subjects learn strategies before being tested and having them work to a standard the tests more accurately reflect work abilities.

This research used methods drawn from linear algebra to compute the Action Set Worker Profile rather than a regression model approach such as was used in Kapur and Liles (1982) and Masud et. al. (1985). For every job modeled with regression equations (i.e., AMI method) a group of twenty subjects is required with disabilities both qualitatively and quantitatively similar to the expected client. These twenty subjects must not only take a full AMI battery but must also be trained and timed on every job to be considered for the client. Worker Profile should be generalizeable to any job which can be described by the same subset of Modapts elements used to describe the tests completed by the client.

Regression modeling of the AMI tests was not sufficiently sensitive to allow new time values to be individually assigned to the Modapts elements (Masud et. al., 1985). Masud et.al. could only generate field factors or percent normal times for complete tasks. Ward (1988) used a combination of Modapts test standards and algebraic methods to modify the performance times of each Modapts-like element for the individual client.

The least squares method used in that study was more sensitive to individual element times than regression methods. An element by element modification should assist in job simplification and work modification to an extent not possible with a single job time multiplication factor.

LEARNING EFFECTS

Amazingly little is known about the effect of practice on the manual performance of physically disabled workers. In the search for information on the learning patterns exhibited in rehabilitation related training two philosophies were encountered: "the disabled are so different from one another that nothing can be generalized across the population"; and, "the disabled are no different than anyone else, they learn the regular way." Given that most rehabilitation training uses a test, train, and retest cycle that continues until successive testings, "show no additional improvement," it would seem that someone would have investigated the learning patterns. Additionally, how can it be determined that a student has reached maximum potential if performance variance is not known?

All of the following research has involved only able-bodied workers but it raises some interesting possibilities for consideration in vocational testing and training for the disabled worker.

Differential learning rates. Work elements categorized as transportive are effected differently by practice in able-bodied workers than are those elements which are primarily manipulative in nature (Barnes and Mundel, 1938). Transportational elements are those that involve moving the hand from one location to another. Manipulations occur as terminators to transports and directly effect the environment. In reaching to a bin of screws, grasping one screw from the bin, moving it to an assembly and inserting it into a hole the reach to and move from the bin are transports and, the grasping and insertion of the screw are manipulations. An able-bodied worker who performed this simple task repeatedly demonstrates a whole task improvement approximating the classic learning curve. In the able-bodied worker the transports are performed at about the same rate on the first try as they are performed on the thousandth try - practice does not significantly change transport speeds.

Improvement and change in feedback. Almost all of the learned improvement occurs in the manipulations; however, the manipulations are not performed uniformly faster, rather, delays associated with visual feedback are eliminated (Smith and Wargo, 1963). That is to say, the hands/fingers do not move faster when they are moving but they stop less frequently during manipulations. With experience the eyes stop interrupting on-going events and anticipate actions - looking ahead to the next step.

Mean shifts but range constant. The range of work element performance times does not change with learning but the mean performance times shift from the slow end of the range toward the fast end of the range (Salvendy and Seymour,1973). Early in training the worker tends to make more fumbled efforts, visual checks and corrections but occasionally the parts fall readily into place. With practice the fall-into-place events become more common and the fumbles, while rare, still occasionally occur.

Variability proportional to improvability. The more variable the performance of an element the greater the opportunity for learned improvement (Cox, 1934). Three possible conditions exist: little variance with performances tightly grouped at the slow end of the range, little variance with performances tightly grouped at the good end of the range, and highly variable performance over the entire range. In the first case there may be a physical limit to performance and training will not help; even if learned improvement is possible good performance may be so rare that it is difficult to fix as the norm. When performance is already consistently at the good end of the individual's natural range, if range is truly constant, there is little room for improvement. In the highly variable case desirable performance occurs with sufficient frequency that it can be used as an achieveable target and mean performance can be changed if the available improvement is realized.

DISCUSSION

During the last century and a half functional assessment of the disabled has advanced significantly. The progression has been from one-on-one therapy, through a period when a single rehabilitationist worked with a group of disabled clients, to the current system of a team of specialists working with a class of disabilities. These changes have required constant updating of assessment methods.

Over the last twenty years assessment efforts have attempted to quantitatively measure the client's abilities with results in a form both useful to the rehabilitation engineer and communicable to the team members with nonengineering backgrounds. Hasselqvist (1971) and Chyatte and Birdsong (1971) all felt that a useful functional test must lie somewhere between the extremes of work sampling and simple, basic motion measurement. They also thought that the necessary techniques could be found in the industrial engineering approach to work analysis. Mink (1975) carried this work forward by suggesting that a team of specialists should make the assessment based on PTS analysis of functional tests.

Brickey (1981) found that MTM standards for work could be communicated to and beneficially used by even severely retarded subjects without significant increase in either training time or error rate.

A major change in assessment philosophy accompanied the development of the Available Motions Inventory (AMI). The AMI (Dryden, Leslie and Norris, 1984) was developed at Wichita State University to break traditional work sample testing into more basic abilities testing. Work samples can be viewed as a series of tasks; failure on any of the sequential tasks results in failure of the whole test. Such failure tells the tester little, and the resulting report conveys even less information to a reader. The work sample is a qualitative measure of the client's ability to interact successfully with a specific environment. The AMI was developed to present the client with a series of independent tasks making a quantitative analysis possible. The AMI report is intended to break out and measure the various elements of work so that they can later be reassembled by the counselor or engineer to match the client to a job or to redesign a job to use the clients abilities (Malzahn and Kapur, 1980).

The AMI testing breaks work measurement into smaller tasks than previous work sampling methods allowed (Rahimi and Malzahn, 1985). Client reports from the AMI give detailed information about reach, reaction times, rates, setting accuracy, and strength used in machine monitoring and light assembly tasks. The standard AMI report contains several sections. The first six pages present an overwhelming collection of data, from which the mean position scores and mean subset scores are very useful to an evaluator. The last page of the report has charts for strength and speed factors. While the AMI tasks are more appropriate in vocational evaluation than were previous medical diagnoses or work samples, the motion class report suffers from some of the same shortcomings as previous methods. The AMI motion class report breaks activities into muscle groups and physiological motions which do not relate directly to work actions. The method used in translating AMI tests into the report output assumes that the physical motions used by the disabled clients are the same as those that were used by the able-bodied subjects in the test sample used to establish the standards.

Three basic, unsubstantiated performance assumptions were made during the AMI standards development. In using an able-bodied population to define the AMI standards it is assumed that the disabled client will use the same motor groups to accomplish the task, that the motion times will be in the same proportion for the disabled as they were for the able-bodied and that the learning curve will be the same for all clients. In many ways this last assumption is the most bothersome because it is hidden in the AMI software. Each control panel is used repeatedly during an AMI test and the standards assume that each repetition will be accomplished faster than the previous trial. A user who performs each of the repeated trials on a panel in the same time per trial is awarded successively lower Z-scores.

The assumption that disabled clients perform AMI tests with the same motions used by able-bodied from the standard population is violated not only because it is physically impossible but also by test procedure. In AMI testing the client is not specifically told how to perform each test, only the desired results. In an Action Set Model this does not present any problem but given the AMI assumption that all users will perform a test with the same set of motions can create a false picture of the client's motion capabilities.

AMI results have never been easy to use in the job selection and redesign process because the Motion Class Standard does not fit well with the industrial engineer's model of work. Since Hasselqvist (1971) and Chyatte and Birdsong (1971) some bridge between functional testing and work measurement has been sought. Mink (1975) and Malzahn and Kapur (1980) tried to use MTM as the connecting link. Winkler and McQuaid (1984) and Masud, Malzahn and Singleton (1985) have shown Modapts superior to MTM-2 in developing AMI standards. In both Masud et al. (1985) and Heyde (1983) use of Modapts with short cycle tests was found to produce a systematic bias in predicting work times. Short cycle tests appear to be performed at a faster rate than more complex, less frequently repeated tasks. Expected work times based on simple tests need to be adjusted for this bias. Each of the reported efforts at finding a PTS standard for the AMI tests has sought a single "field factor" which could be applied to the overall work performance rather than to modify the individual time requirements of each Modapts motion. Heyde's (1983) suggested adjustment was to assume 7 mods per second on the job but 10 mods per second during testing.

Kapur and Liles (1982) and Rahimi and Malzahn (1984) attempted to relate AMI tests to work performance by developing regression models. Although this modeling approach has been more successful than most of the other efforts in predicting work time, a new model must be developed for every standard of every job by using about twenty subjects with the same disability level as the intended client. Each job model requires at least a week of subject testing. Models have not been generalizeable to redesigned jobs nor to individuals with different disabilities or different levels of the same disability.

Modapts standards are desirable both because they have proven more accurate than other PTSs tested and because Modapts is easy to teach to new users. Currently Workability is the only Modapts based ability test for the disabled worker. While it is intended to generate quantitative results, the Workability report is very subjective and only gives very general predictions of employability by classes of work.

In Ward (1988) two mathematical models of the disabled worker were developed, tested, and statistically validated. Each of the models used a vector of real numbers to profile the worker in its own n-dimensional space. The two models differed in their representation spaces with the Motion Class Model using the more conventional physiological approach to work using a 14-tuple matching the AMI motion space to describe the worker. The Action Set Model used a norm-independent 12-tuple of Modapts-like actions to describe accomplishments without attempting to determine how the worker achieved those actions. Statistically both models proved good predictors of performance times for four tasks in a laboratory test.

Although in the laboratory the two models proved equally valid one of them, the Action Set Model, has more desirable characteristics for use in industrial placement of disabled workers. As in all earlier attempts to use AMI testing in the functional assessment of disabled workers the Motion Class Model tested required the collection of parametric information for any job modeled. The statistical analysis of jobs being modeled by the Motion Class Model is significantly simpler than was the case for previous AMI regression models but the necessity of collecting the data cannot reasonably be eliminated if Motion Class Standards are to be used. The AMI reliance on statistical methods is inherent in any conventional use of that apparatus because the AMI test standards and job descriptions use a motion class system. It is virtually impossible to develop an AMI standard without extensive observation of people performing the task many times. When observation is used to develop motion class standards difficulties arise from the fact that different observers of a single action perceive a single subject using different motions and different subjects do in fact use different motions to accomplish the same actions.

The Action Set Model, however, eliminates the need for statistical data collection of job performance. Because the Action Set Model is based on a Modapts-like set of work elements and does not attempt to track or dictate how results are to be accomplished, job descriptions can be developed in Modapts terms. Modapts is specifically organized to allow job designs to be planned rather than observed. Unlike any previous system for predicting disabled worker performance the Action Set Model allows the time per action to be calculated algebraically. By describing only the work actions that need to be performed and using a Worker Profile of action times uniquely determined for the individual the Action Set Worker Profile is truly a norm-independent model.

In Ward (1988) the Action Set Worker Profile has a few shortcomings which need to be addressed. The one relative advantage of the AMI based Motion Class Model is that during worker testing only test times need to be recorded while; the Action Set Model attempts to model user actions it is necessary to capture both test times and a description of what actions were really performed (not simply what was intended). During the experiment subject actions were recorded on videotape and job descriptions were written by reviewing those tapes after the test was completed. Because Modapts action descriptors were used for these test standards, this activity was not overly time consuming. Three solutions to this problem appear plausible, the test subjects could be instructed to perform to a standard, the tests could be simplified to allow descriptions to be written as the subject performs, or the use of videotape can be retained.

In this study the test procedure used to solve for the individual Action Set Worker Profile action times required the use of the AMI apparatus and tests. The lack of availability of AMI apparatus and the training necessary for testers will probably limit the appeal of this type of testing in industry. Fortunatly the Action Set Worker Profile appears sufficiently robust so as to allow the use of alternative inputs to be used in place of the AMI tests for the calculation of action times. It appears that all that is required of a test set is that the Action Set matrix be invertable. Clay (1987) and Heyde (1983) have developed simple test routines using commonly available materials which could be easily adapted as inputs to the Action Set Model. Heyde (1983) has described a system he calls Workability that uses a set of simple tasks involving readily available objects that use all of the Modapts actions. A set of tests like those used in Workability should be perfectly adequate for the Action Set Worker Profile. The Action Set Model is more flexible than Workability so not only could Workability tests be used but if a particular subject demonstrated difficulty with a given test it could be modified on the spot without loss of accuracy. Clay's tests have not been described in Modapts terms but should also be usable as Action Set Model inputs with only a moderate level of effort required to appropriately format them.

The structure of the AMI tests is such that while the mean performance time for individual actions can be calculated it is mathematically impossible to determine the variances of the individual action times. With careful balancing of the action mix in a set of tests used as inputs for the Action Set the variances and critical intervals can be computed.

Four points of interest.

- Different work elements are learned at different rates.
- Learning occurs as visual feedback is reduced.
- Range is constant but practice reduces mean time.
- Present variability is proportionate to future training benefits.

These four effects are from research involving only able-bodied subjects. Will they generalize to physically disabled workers? Do the disabled approach the learning curve performance plateau of different elements at different rates? Is visual feedback of equal import and impact on work performance in the disabled? Can reliance on visual feedback be reduced with training? Can variability of element performance times be used to quantify trained performance predictions based on untrained performance? Will part-task variability indicate potential for learning? Can early variability on part-tasks be used to set more realistic targets for training than the current use of "normal" performance? Will training on the part-tasks with the greatest variance result in better use of training time than the current practice of training the part-tasks that deviate most from "normal" performance?

CONCLUSION

To be of high utility to the industrial engineer an assessment tool must produce highly quantified results, be easy and inexpensive to apply, and predict performance on a large number of jobs. Whether job performance is computed as units per hour or dollar return on man-hour the ability to predict performance in some quantifyable measure is important to an employer. An assessment system which requires many hours to apply is not going to be welcomed by the employer who can hire someone other than the disabled client without the bother or expense of testing. If an assessment only applies to some small number of jobs it will not gain wide spread use in a manufacturing environment that is emphasizing flexibility as a means of staying competitive.

Most early functional assessment tools were essentially qualitative in nature. Although the assessment process made some relative job comparisons possible a complete ranking of potential jobs could be prohibitively expensive. Qualitative predictors make the job selection effort more difficult and costly because each possible job must be evaluated and compared to every other possible job; included in the comparison must also be all possible variations on job methods. This heuristic approach to job placement may have been satisfactory in state supported, or charitable, institutions whose primary goal was to remove the disabled from the real world and give them make-work to keep them occupied, but it lacks industrial support. If the goal of the assessment procedure is to mainstream the disabled then the assessment tool must work in the competitive world of modern industry. To justify the employment of anyone, industry must be convinced of the return on investment, not simply shown that a specific job is the best available job for the individual.

An assessment tool which is expensive to apply is not going to get much play. The types of expenses that have typically been associated with assessments have included initial equipment costs, storage space, set-up time, assessor training, analysis of results and test/retest requirements. The worst offender for this type of cost is probably the work sample method; however, all the current test procedures cost more than most employers are willing to dedicate to the employment of the disabled! What is needed is a system that can be used by the typical human resources staff member without extensive training. Equipment purchase cost and storage requirements should also be minimized.

Another expense that industry cannot and will not tolerate is the extensive collection of statistical data on every job. Although the use of regression equations has worked very well in the academic setting it will never be popular with industry because the method requires many test subjects of each level of disability to perform each job many times. The return on investment for this type of data collection is unlikely to produce a profit. In addition to the problem of collecting data on many jobs, regression methods do not allow for the modification of the work method to accommodate an individual nor do they fit well with flexible manufacturing environments.

Assessment results must be generalizeable to a large number of jobs with minimum application expense. Even an inexpensive test that can only be applied to one specific job will result in a large application expense both as a result of testing many people until one is found for the specific job and because of the number of different tests which an individual must complete before being placed in an appropriate job. To be competitive in industry a single test application of the assessment tool must generate a result which can be used on many different existing jobs and which can be used to modify those existing jobs to make them more productive for the disabled individual.

To be accepted by industry a functional assessment tool must accurately predict worker performance on real jobs, and be easy and inexpensive to use.

RESEARCH PURPOSE

Background. Industrial engineers rely on worker modeling to design work methods. Most worker modeling is based on one of a number of predetermined time systems (PTS) of elemental work descriptors. PTS are simply sets of work elements sufficient to describe any of a class of jobs, and the mean performance times for each element. Job performance time is calculated by summing the job's constituent element times.

Models of the disabled worker take one of three forms: medical; categorical; or, work sample. Medical models describe the anatomical or physiological extent of the disability. Categorical models classify the type of activity the individual should be capable of performing. And, work samples involve testing the person one job at a time until a good fit is found. None of the existing models of the disabled worker is PTS based and none of them predicts performance in terms usable by the industrial engineer on the shop floor.

Ward (1988) involved the development of a limited PTS based model by the determination of the mean performance times of work elements for easily mastered tasks. Undemanding tasks were used because of time constraints. Work element mean performance times were calculated because the test method used did not permit the calculation of element variances. The inability to assign variance to individual work elements was a result of the use of 29 different dexterity tests, each of which was timed once per subject. Another reason for avoiding measurement of variances was that there is some debate as to the utility of work element variance in performance prediction.

Because that work was well received this dissertation will continue to explore and refine the use of industrial work descriptors in the vocational rehabilitation of workers with disabilities. The areas of greatest interest for further investigation were the sources and implications of work element variance, and the impact of practice on whole and part-task performance.

PREVIOUS WORKER PROFILE APPROACH

This research begins where Ward (1988) ended with the testing and modeling of disabled workers for vocational assessment and rehabilitation. This study refines the Action Set Model put forward in Ward (1988) and explores the effect of learning on the assessment and work assignment process. This methodology section describes the previous work and then sets forth a more focussed approach. The two Worker Profile Models are reduced to one; the 29 AMI tests are replaced with twelve tests; the single test technique will be replaced by a multiple test approach which extracts changing parametric values; and the learning effect will be documented.

Experimental Design. Two groups of subjects were each tested for manual dexterity using the standard AMI apparatus. The scores for each subject were used to drive two models of worker behavior. These two models were used to predict performance on each of four work tasks. Each subject was timed while performing the four work tasks. The primary analysis in that research was a comparison of the predictive value of each of the two models for each of the four work tasks.

Standards

For a discussion of the AMI Motion Class Standard see Ward (1988).

Modapts standard.

The Modapts standard is a vector (or 12-tuple) representing the number of repetitions of each Modapts element in a task. The Worker Profile is a vector (or N-tuple) of weights per repetition for each of the standard's elements. The dot product of the two vectors is the total time required to perform the task if performed to standard. AMI test #1 (CLH SLIDE switches) can be standardized as:

$$\text{time}(\#1) = [\#M1\ \#M2\ \#M3\ \#M4\ \#G0\ \#G1\ \#G3\ \#P0\ \#P2\ \#P5\ \#J0\ \#X4] * [wp1\ wp2\ wp3\ wp4\ wp5\ wp6\ wp7\ wp8\ wp9\ wp10\ wp11\ wp12]^T$$

Where:

time(#1) is time to perform test #1 (CLH SLIDE switches)
#M1 is number of occurrences of M1 (finger moves) in test 1
#M2 is number of occurrences of M2 (hand moves) in the test
#M3 is number of occurrences of M3 (forearm moves)
#M4 is number of occurrences of M4 (whole arm moves)
#G0 is number of occurrences of G0 (finger touches)
#G1 is number of occurrences of G1 (simple gets) in the test
#G3 is number of occurrences of G3 (multiple feedback gets)
#P0 is number of simple puts (drop object in area)
#P2 is number puts with alignment in the test
#P5 is number of puts with multiple alignments
#J0 is number of finger rolls (repositioning in hand)
#X4 is the number of times the hand exerts force

wp1 time required per M1 (for able-bodied wp1 = 1/7 sec).
wp2 time required per M2 (for able-bodied wp2 = 2/7 sec).
wp3 time required per M3 (for able-bodied wp3 = 3/7 sec).
wp4 time required per M4 (for able-bodied wp4 = 4/7 sec).
wp5 time required per G0 (for able-bodied wp5 = 0)
wp6 time required per G1 (for able-bodied wp6 = 1/7 sec).
wp7 time required per G3 (for able-bodied wp7 = 3/7 sec).
wp8 time required per P0 (for able-bodied wp8 = 0 sec).
wp9 time required per P2 (for able-bodied wp9 = 2/7 sec).
wp10 time required per P5 (for able-bodied wp10= 5/7 sec).
wp11 time required per J0 (for able-bodied wp11= 0 sec).
wp12 time required per X4 (for able-bodied wp12= 4/7 sec).

If the actual standard for test #1 (CLH Slide switches) is: (see Appendix E)

#M1=4 #M2=7 #M3=1 #G1=6 #P2=6 (all others = 0)

and Worker Profile for able-bodied: (see Appendix F)

wp1=1/7 wp2=2/7 wp3=3/7 wp4=4/7 wp6=1/7 wp7=3/7

wp9=2/7 wp10=5/7 wp12=4/7 (all others = 0)

Then the dot product = time required for normal able-bodied subject to perform test #1:

time(#1) = 4*1/7 + 7*2/7 + 1*3/7 + 6*1/7 + 6*2/7 (sec).

= 39/7 = 5.67 second expected performance time

Actual performance for 47 able-bodied subjects averaged 5.9 seconds. The 9 able-bodied subjects in this study averaged 6.0 seconds.

Representing the AMI tests in matrix form:

$$\begin{array}{c} t_1 \\ t_2 \\ t_3 \\ . \\ . \\ . \\ t_n \end{array} = \begin{array}{ccc} a_{11} & a_{12} \ldots & a_{1m} \\ a_{21} & a_{22} \ldots & a_{2m} \\ a_{31} & a_{32} \ldots & a_{3m} \\ . & . & . \\ . & . & . \\ . & . & . \\ a_{n1} & a_{n2} \ldots & a_{nm} \end{array} * \begin{array}{c} wp_1 \\ wp_2 \\ wp_3 \\ . \\ . \\ . \\ wp_m \end{array}$$

Where:

t_1 = time(#1) = time to perform AMI CLH SLIDE switches
t_2 = time(#2) = time to perform AMI CLH ROTARY switches
.
.
.
t_n = time(#n) = time to perform n th AMI test
(n = maximum number of AMI tests used)

a_{11} = number of repetitions of M1 in AMI test #1
a_{12} = number of repetitions of M2 in AMI test #1
.
.
.
a_{1m} = number of repetitions of element m in AMI test #1

a_{21} = number of repetitions of M1 in AMI test #2
a_{22} = number of repetitions of M2 in AMI test #2
.
.
.
a_{2m} = number of repetitions of element m in AMI test #2

a_{n1} = number of repetitions of M1 in AMI test n
a_{n2} = number of repetitions of M2 in AMI test n
.
.
.
a_{nm} = number of repetitions of element m in AMI test n
n = number of AMI tests used
m = number of different Modapts elements
needed to describe tasks

wp_1 = time used by subject for Modapts element #1
wp_2 = time used by subject for Modapts element #2
.
.
.
wp_m = time used by subject for Modapts element m

For the i_{th} AMI test the equation becomes:

$$t_i = \Sigma (a_{ij} * wp_j)$$

In matrix form:

$$[T] = [A]*[WP]$$

To solve for [WP] premultiply each side of the above equation by $[A]^{-1}$, the pseudoinverse of [A]. To test the validity of the computed [WP] develop a standard for a job and calculate the dot product of the standard and [WP] and compare this to the subject's measured performance on the job.

Solving for unknown [WP] from known values of [T] and [A]:

$$[T] = [A] * [WP]$$

$$[A]^{-1} * [T] = [A]^{-1} * [A] * [WP]$$

$$[A]^{-1} * [T] = [I] * [WP]$$

$$[A]^{-1} * [T] = [WP]$$

Differences between Modapts and the Action Set.

Action Set identifiers (Table 2) were named to make their relationships to Modapts identifiers (Table 1) as intuitive as possible. In most cases the identifiers look exactly like their Modapts counterparts; however, the Action Set identifiers are defined somewhat differently than are Modapts identifiers. Another major difference exists between Modapts identifiers and Action Set identifiers; Modapts identifiers each have a predetermined time associated with them while Action Set identifiers are never linked to a performance time unless a Worker Profile has been computed for a particular person. Action Set identifiers have neither a predetermined action performance time assigned to them, nor are they assumed to have particular performance time ratios.

Table 2. Operational definitions of Action Set identifiers.

M1 - 1 inch change in the point of control (i.e., typically a finger for most workers, but it could actually involve any convenient body part or tool if finger use was not possible)
M2 - 2 inch change in the point of control (i.e., typically a hand)
M3 - 4 to 6 inch change in the point of control
M4 - 8 to 10 inch change in the point of control
G0 - Gain control by simple contact (i.e., at end of move, it would typically involve bringing a finger into contact with something but if a finger was not convenient for use the G0 control could be made with any body part or tool)
G1 - Gain control with single M1 type action
G3 - Gain control with multiple M1 type actions
P0 - Release control with no additional feedback (e.g., drop object in a bin, set object aside at any open space)
P2 - Place object with one dimensional feedback (i.e., place object anywhere along a line, place a large washer on a small bolt)
P5 - Place an object with two dimensions of feedback (e.g., start a threaded nut on a bolt, place an object at the intersection of two lines)
J0 - Reposition an object while it is being transported (e.g., regrip a pencil after picking it up while moving it toward a piece of paper, correctly orient a nut that has been taken from a bin so that when it arrives at the end of a bolt it correctly engages)
X4 - A exertion of force that causes some delay (e.g., pressing an already positioned thumbtack into a wall, changing the setting of a resistant switch)

Action Set identifiers are used to describe what actions (not what motions) are necessary to perform a particular task. This differs radically from the original Modapts definition that linked certain body parts (and their motions) to specific Modapts identifiers (see Table 1). The Modapts M1 descriptor specifies a finger motion, or an action which could be accomplished by a finger motion; it also assumes this activity will require about 1/7 second. The Action Set M1 involves a shift of control of about 1 inch, but makes no assumptions about how that control is maintained nor about how much time will be required. The term "point of control" is used in Action Set MOVEs rather than the terms finger or hand as is the usual case with Modapts to note the allowance for the use of any convenient body part or external device in the performance of any test or work task. The Modapts M2 assumes a motion that could be accomplished by moving the hand from the wrist; the M2 further assumes that a time of about 2/7 seconds will be required and that an M2 will take about twice as long to perform as would an M1. The Action Set M2 involves a shift of control of about 2 inches; no assumptions are made about how long in general this action would require. All Action Set time specifications are contained in individual Worker Profiles. The Action Set description relates only to the action sequence needed to accomplish a task; it specifies neither the body parts which will be used nor the time required for the actions.

All time requirements are captured in the Action Set Worker Profile, and the time elements of a Worker Profile only relate to the individual for whom they were computed. Unlike Modapts which is geared to the normal behavior of typical able-bodied workers, Worker Profile, focuses on the unique behaviors of individuals who may differ radically from the average worker. Why then is the Action Set Worker Profile designed to "look" like Modapts? The Worker Profile can be used as an extention of Modapts. Once a Worker Profile has been computed for an individual worker it can be used to modify the action times used in a Modapts job description to estimate the individuals performance time on the job.

The Action Set Worker Profile uses two constraints and one action not found in Modapts. Modapts identifies a simple 1 inch motion of the fingers as either an M1 or a G1 depending on the context of the action. The repeated raising and lowering of one finger to press a push button would typically be described as a series of M1G0 M1P0 actions; if on the other hand, the motion began at some distance from the button and the hand were first moved into position near the key and then the finger extended to press the button the same action could be described as M3G1. If a finger motion is preceded by a hand motion it could be called a G1, if only the finger moves the action of pressing the button could be called an M1. Same action, two names. Therefore, in the least squares calculation of an Action Set Worker Profile the time required for M1 actions and G1 actions is by definition approximately equal. Similarly, G0 and P0 are in some cases interchangeable and are always used only as terminator actions to mark the end of one motion and the beginning of another. These two terminator actions require no additional time beyond that used in the motions that must immediately precede and that must immediately follow them. The Worker Profile calculation includes a constraint to limit the amount of time that can be assigned to either P0 or G0 (i.e., they are forced to be as close to zero as practical within the least squares calculation).

The J0 action is not used in traditional Modapts descriptions. Normally, a Modapts juggle motion would either be included in a job description as a J0 if it occurred at a time when no other action was occuring, or else it would be covered (and not charged) by some simultaneous activity (which of course would itself be charged for the time involved). In observing videotapes of individuals performing AMI tests it was apparent that juggles are not all-or-nothing events. Modapts would have assumed all of the J0 actions used in the AMI tests to have occured simultaneously with some other chargeable action and, so, not be chargeable themselves. Their occurances did infact add time to the test performance (not however a full 2/7 seconds). To avoid biasing the time estimates for the simultaneous motions which occured while the juggle actions were being performed an additional action descriptor, J0, was added to each test where a juggle occurred. If the Modapts assumption of unchargeable simultaneous juggles was correct then the least squares method should have assigned a Worker Profile time of zero to the J0 actions. In fact, some subjects produced J0 times close to zero and were quite successful at performing the juggle action simultaneously with some other action (see, for example, subjects a1 or a2 in Appendix F). Others, required significant additional time to perform tasks which included juggle actions (see subjects a8, b3 or b7 in Appendix F). The ability to perform the juggle seems to be highly individualistic. One final note on the J0, the use of the "2" in the J0 descriptor name in no way effected the amount of time assigned to the worker Profile because it is simply an action name. The "J0" name was used simply to note the deviation from normal Modapts nomenclature.

Standard development.

To establish Modapts standards for the AMI tests a series of four subjects was given the full battery of AMI tests. Heyde (1983) discusses standard development for Modapts job descriptions. He recommends the use of one trained worker, repeating the activity while the work study person takes notes. The work study person then develops the standard and again observes the worker to verify the standard. Lacking trained workers Heyde suggests that an experienced work study person should develop a well reasoned standard and then have one or more workers trained to the standard to verify it. Verification in the case of a new job consists of developing a standard which, if followed exactly, will result in completion of the job. The standard in this case is not necessarily an optimal solution, but rather may be used as a first approximation for training and to coordinate work efforts so that all workers are doing the same work. Each subject was instructed in the preferred standard and then allowed to modify that standard to their own optimal method. Four able-bodied subjects were observed to set the standards. On tests where all members of the standard setting group used the same test strategy that method became the standard for instruction. Where several approaches to a test were used, the most efficient method, in terms of hand movement, was selected as the standard. Each of the four subjects had several opportunities to take each test. Experience with the AMI shows that individual performance times tend to approach a limit after four to six trials. Each of the test subjects approximated Heyde's "trained worker" after several trials. The primary reason for using more than one subject for setting standards was to demonstrate different solutions from which one could be selected for the verification portion of the study. This group of four subjects was videotaped during testing, and standards were set by analyzing the tapes.

The AMI test instructions given to subjects included information about standards. Subjects were encouraged to use an optimal sequence of moves in performing AMI tests and work tasks. For most of the subjects, performance time was minimized by using the standard, but if the subject could demonstrate better performance by using a different sequence of moves that method was used for the subject. The least squares analysis of AMI results used a standard for the actual sequence of motions used by the individual to perform the test.

Worker Profile Models

Motion Class Model.

The Motion Class Model requires motion class scores, a motion class job standard and parametric information about normal performance of the job. The motion class scores are generated by the Wilhelm (1985) software from standard AMI test scores. For any job to be modeled a job standard must be generated and mean and standard deviation for normal able-bodied performance measured. The Motion Class Profiles are Z-scores for the individual being modeled. The Motion Class Standard is a 14-tuple of weights for the 14 motion class elements. These weights must be normalized to sum to one to be used by the model. The dot product of the Motion

Class Profiles and the job standard estimates the individual's Z-score on the job being modeled.

Motion Class Model:

$\sum$Motion Class Standard = 1.0 (normalized)

(weighted Z-score) = $\sum$(Motion Class Standard * Motion Class Profile)

Predicted job time = (mean job time) +

(weighted Z-score)*(job standard deviation) Action Set Model.

The Action Set Model uses a Modapts formatted Worker Profile and a Modapts standard for the job being modeled to predict performance times. The Action Set Worker Profile is computed by performing a least squares transformation on a set of AMI test performance times for the AMI control and assembly tests. The Action Set Worker Profile is a 12-tuple of performance times for the 12 Modapts elements needed to describe the AMI control and assembly tests. The Modapts job standard is a 12-tuple of the number of occurrences of each of these same 12 Modapts elements for the job being modeled.

Because the Worker Profile being solved for in this instance is of lower order than the test set being used, the problem is under constrained and additional constrains can be added to the least squares computation. Two constraints were added to improve the utility of the solution, M1 and G1 were forced to approximate equality and the G0 and P0 times were forced toward zero. M1 and G1 bear an interesting relationship to one another in Heyde's (1983) original definition of Modapts; each is a one inch move of the fingers, differing only in the context in which the action in taken. An M1 is a move occuring between the gaining and release of control of an object. G1 is the one inch move required to gain control of an object which only requires the fingers to be closed around the fully exposed object. The M1 and G1 values are forced to be equal because in reality there are no differences between the two actions; that is to say, Modapts would lose none of its utility if the G1 action were removed from the Action Set and M1 were substituted for it on a one-to-one basis. The P0 and G0 actions are used in Modapts as punctuaters to indicate the end of one move and the beginning of another. Again, the difference between the two is merely contextual, with the P0 indicating the termination of one move and the beginning of the next were a relinquishing of control occurred (with no time passing between the end of one move and the beginning of the other). Likewise, the G0 is used where one move ends and another begins, control of something is assumed, and no time passes between the end of one move and the onset of the other. The G0 and P0 times should be zero because by definition they only represent the end of one action and the transition to another. Applying these two constraints had the additional benefit of eliminating most of the negative action times. Negative times were an artifact of the use of AMI tests which are not optimally balanced for use in a least squares solution.

Action Set Model:

Predicted job performance time = [Modapts job standard]

$\times$ [Action Set Worker Profile]^T

Software Development

An IBM PC AT was used for data reduction, AMI processing, to set AMI Modapts standards interactively, to prepare AMI results for least squares processing, to generate both Motion Class and Action Set Worker Profile predictions, and to conduct preliminary statistical analysis. With the exception of the AMI score processing, all of these functions were performed by software developed especially for this research effort.

Subjects

Two groups of subjects were used in Ward (1988) Group A consisted of nine college student volunteers selected randomly from the student population at Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Group B consisted of nine disabled workers enrolled in a work adjustment training program at the New River Valley Workshop, Inc., Radford, Virginia. Four members of each group were females. All subject volunteers were paid five dollars per hour for participating in the study. Group A subjects spent an average of four hours in the laboratory. Group B subjects averaged six hours of participation.

The Experiment

A battery of AMI tests was given to the eighteen subjects. After completing the AMI testing each subject was timed on four work tasks.

The purpose of the experiment was to determine if actual work times could be predicted by use of the Worker Profile Models. On both the AMI tests and the work tasks the subjects were instructed in a preferred standard method. The Wilhelm (1985) software was used to generate the Motion Class profiles and a least squares analysis of AMI test results was used to calculate Action Set Worker Profiles. Both sets of Worker Profiles were used to predict the subjects' performance time on the work tasks.

The four work tasks used in that study consisted of two assembly tasks and two disassembly tasks. Task 1 was the disassembly of six nut/bolt combinations. Each of six .5 x 1.5 inch hex headed set bolts was presented to the subject on their nonpreferred side (left side for a right-handed subject). Three nuts had previously been equally spaced along the shaft of the bolt. The task was to lift the bolt/nut combinations from the surface on the nonpreferred side with the nonpreferred hand and to use the preferred hand to remove the nuts, one at a time using the finger tips and thumb to turn the nuts. The disassembled nuts and bolts were each placed in a precisely specified location on the work surface (all locations within easy reach of the subject). Task 2 involved replacing three nuts on each of the six bolts. The bolts were initially laid on a flat surface to the subject's nonpreferred side and the nuts on the work surface to the subject's preferred side.

Task 3 was the disassembly of three plug/adapter combinations. Each of the three assemblies consisted of two 3-pin electrical plugs and an appropriate adapter (electrical fitting). The previously assembled combinations were presented directly in front of the subject. Each was in turn picked up with the nonpreferred hand and the two plugs in each were extracted with the preferred hand. Disassembled plugs were placed in a bin directly in front of the subject at approximately shoulder level. Disassembled adapters were discarded to the subject's nonpreferred side on the work surface.

Task 4 used three three-pin electrical fittings and six three-pin plugs. Each adapter accepted two plugs. The task began with the six plugs in a raised plastic bin on the subject's preferred hand side and the adapters laid out on the work surface to the subject's nonpreferred hand side. The subject using nonpreferred hand to hold the adapter and preferred hand to manipulate the plugs one at a time put two plugs into each adapter, laying them aside as they were completed.

Goals. The goals for this research are:

- Develop an easy to administer test set.
- Generate unique worker profiles of each subject.
- Design test results to be compatible with existing PTS.
- Determine utility of model in training programs.

Engineering models of work design provide quantifyable, generalizeable metrics and models of both worker and work. Predetermined time standards (PTS) allow the modeling of an able-bodied worker with such ease and accuracy that make practitioners forget that they are indeed working with a model.

Although learning occurs in most work situations little note is made of this ubiquitous process.

The present study has as its objective to modify the basic PTS model to accommodate disabled workers. The resulting Worker Profile is intended to assist in the assignment of specific jobs to individual workers; find efficient, comfortable work methods; determine trained performance before the onset of training; develop training programs that accelerate the training process; and, in general, remove some of the mystery from the vocational assessment of disabled workers.

RESEARCH RESULTS

FIVE EXPERIMENTS IN DISSERTATION

The Worker Profile research for this dissertation was conducted as 5 experiments:

- Establish learning patterns of disabled and able-bodied
- Develop appropriate tests and validation tasks
- Test and validate able-bodied to establish base line
- Test and validate model on disabled workers
- Validate model in sheltered workshop

THE SUBJECTS

Three populations of subjects were sampled for this research: able-bodied students, disabled students, and disabled workers at local sheltered workshops. Some of the able-bodied subjects used in the early stages of this research were unpaid volunteers, all other subjects were paid $5.00 per hour for their participation.

A group of able-bodied subjects was used to develop and validate the test set. The able-bodied subjects were drawn from the Virginia Tech student population. This control group was selected to approximate the gender mix and age range of the disabled subject group. A total of 18 able-bodied subjects was used, 10 were male, all were between the ages of 19 years and 30 years.

The disabled subjects used in this study were selected from the population of physically disabled adults in the New River Valley area. All disabled subjects had multiple sclerosis, muscular dystrophy, or cerebral palsy. The individuals sought were people of working age with degraded manual dexterity but who are actively seeking to enter the work force. Two populations of disabled were sampled those in school and those working in sheltered workshops. The two workshops for the disabled in the New River Valley have been helpful in contacting appropriate individuals for Rehabilitation Engineering experiments in the past and were again cooperative in publicizing our needs for this study. One of the workshops also provided a screening service to eliminate inappropriate subjects from the study (i.e., people without some level of degraded manual dexterity, medically unstable individuals, and subjects with other, possibly confounding, disabilities). Disabled students at Virginia Tech were also recruited and utilized.

THE TEST SET

A set of tests of manual dexterity were developed and used in this study. This set of tests is based on the Workability tests developed by Chris Heyde and on the standard AMI tests. The Workability tests use common household items such as checkers, dominoes, marbles, golf tees, paper cups, playing cards, etc. The objective of each test is to have the subject rearrange objects from a known starting position to a desired goal configuration. The tests vary in the level of dexterity required, the distances over which objects are transported, and the number of repetitions required. A pilot study was used to adjust difficulty to produce a test set that was challenging yet achieveable.

Tests were used within a session to measure dexterity and sessions were repeated to demonstrate the effect of experience or learning on performance for each individual participant.

THE EXPERIMENTS

The research consisted of five experiments. The initial experiment was a determination of the basic learning patterns for industrial assembly tasks by able-bodied and disabled workers. A set of dexterity tests was developed during the second experiment. A base-line study of able-bodied workers was made to determine the quality of the dexterity tests. The main study examined disabled workers performance on the test battery.

And finally, a validation experiment compared model predictions to on-the-job performance for disabled workers.

In the preliminary study of the disabled individual tests were modified to more closely match the residual abilities of the disabled subjects. Dexterity requirements were determined and an estimate of the number of repetitions of each test needed to demonstrate the learning effect was developed. The preliminary study used only disabled subjects and was conducted in a classroom at the New River Valley Workshop, Inc., 103 Duncan Lane, Radford, where all of the participants are currently employed. The first experiment was a preliminary study of the disabled to determine the appropriateness of the tests and methodology for handicapped adults.

The second experiment of the research was used to develop a set of appropriate tests of manual dexterity. Starting with the 29 AMI dexterity tests, the Workability dexterity tests, and tests developed in Ward (1988), tests were compared for learning method, ease of administration, and appropriateness for the subject population to identify 20 tests for use as inputs and for validation of the Action Set Worker Profile Model. In addition to the selection of tests for inclusion in the latter parts of this research specific measures for use as model inputs were identified.

The third experiment established base-line performance for able-bodied individuals and verified the experimental premises for the test set. The baseline study was used to further evaluate the dexterity test set, the validation test set, the two learning methods, and the relative effectiveness of the model for predicting task performance of work requiring varying levels of precision and complexity. The baseline study also provided a basis for performance comparisons in all other phases of the study. The baseline study used 10 able-bodied subjects, 5 of whom were male and 5 female, recruited from the student population at Virginia Tech and was conducted entirely in the Human Assessment Laboratory (519a Whittemore Hall).

Experiment number four was the main study in which disabled subjects were observed performing all tests. Half of the disabled subjects were male and half female. Each of 6 manually disabled subjects repeatedly performed each of 20 selected manual tasks over a 3 day period. Twelve of the tasks were used as inputs to the Action Set Model and the other 8 were used for validation. Learning patterns were studied for all tasks.

The final phase of the experimental portion of this research was a validation study to determine the relationship of test results to on-the-job performance. The validation phase of the experiment used 3 employees at the New River Valley Workshop, Inc. Subjects were all participants in experiment 3 and the Action Set Model parameters calculated in that study were used to predict work performance on the subjects' regular jobs at the workshop.

EXPERIMENT 1: LEARNING EFFECTS

In the pilot study a number of tasks were performed repeatedly by able-bodied and disabled subjects. Five unpaid able-bodied and 3 paid disabled volunteers were recruited to assist in the development of test and training guidelines. Each of the volunteers was given a limited number of tasks to perform and asked to repeat the tasks until improvement ceased. Performance was recorded on videotape and the film examined on a frame-by-frame basis.

The tasks used in this study involved moving small objects from one container to another. Spheres of varying size and weight were placed in one open topped container and the subject moved them one at a time to the other container. Beginning the task with the objects in a container eliminated the need for the subject to search for the objects. Low sided containers with large openings were used to minimize access difficulties. Objects were transferred to another container to control the distance the objects were moved and to prevent their interfering with the subjects' focus on the transfer process. Spherical objects were used to avoid variability in ease of grasping that might be associated with asymmetrical objects. Each subject was tested with balls of a variety of sizes and weights to allow some possible subject*object interactions to be studied.

Analysis of experiment 1

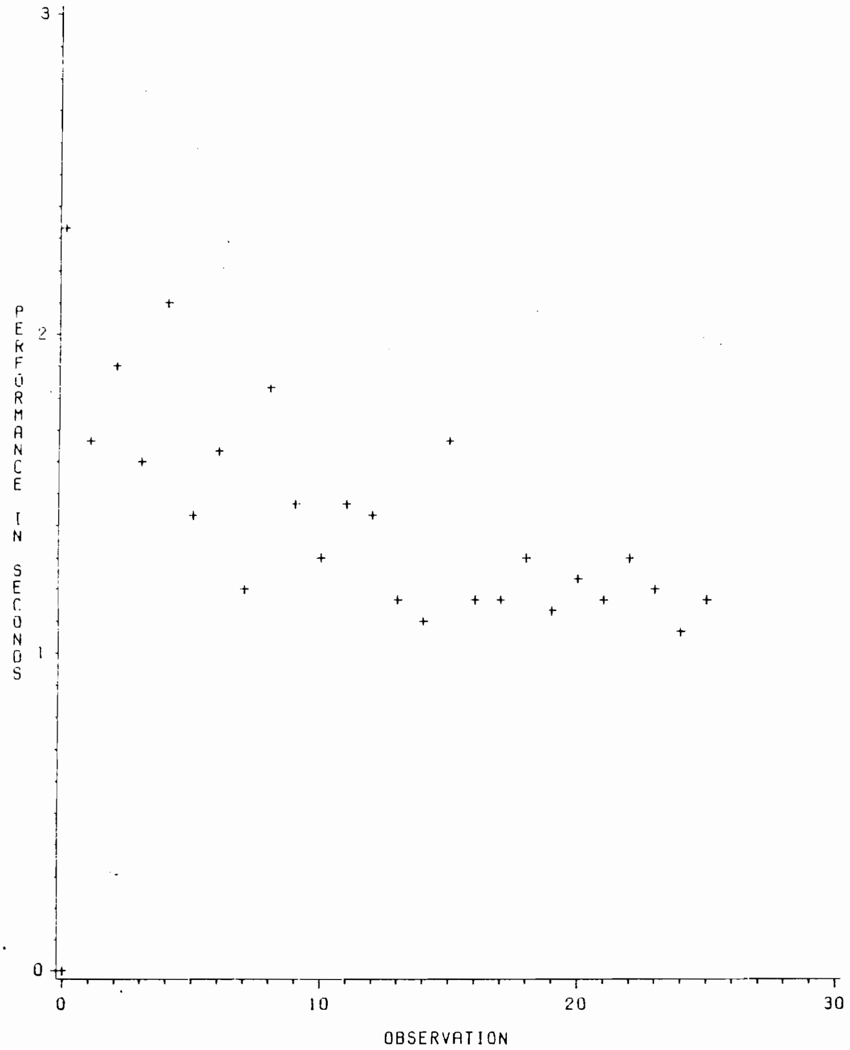
As was expected, both able-bodied and disabled subjects demonstrated the classic learning curve for most whole tasks. Unexpectedly, a second distinct pattern occurred in each group, the two learning patterns will be referred to as evolutionary and revolutionary. The evolutionary pattern of learning occurred when the same work motions were used throughout the training period; overall task performance demonstrated a smooth, continuous improvement but the exact sequence of moves remained constant. In the revolutionary pattern a tactical change appeared in the learning cycle - at some point the subject changed the set of work elements being used. In the revolutionary pattern either movement distances were reduced or manipulation precision was reduced to produce a sudden improvement in performance. With evolutionary learning the Modapts description of work performance remains constant throughout the practice period; with revolutionary learning the Modapts description changes when improvement occurs.

Figures 1, 2, and 3 illustrate the evolutionary and revolutionary learning patterns. In Figure 1 the typical evolutionary pattern shows EARLY BEST performance to approximate LATE MEAN performance. In the evolutionary pattern learning takes place quickly in a smooth continuous process. Occasional late worst performances are infrequent but on the same order of time to perform as early worst cases. In the discrete form of the revolution pattern, seen in Figure 2, a distinct break in performance style occurs after some initial improvement; after the break another period of rapid learning occurs. After the transition in work element sequence occurs worst case performance is rarely as bad as early worst performance; conversely, early best performance rarely approaches late best performances. In Figure 3 the change in performance method is continuous, but after the transition period the task is performed in a more efficient manner than it was before the change. In the continuous form of the revolutionary pattern: final work method is different from the early method; early best performances do not approach the efficiency of late mean performances; late worst cases are not as slow as as early worst case cycles; and the period of rapid improvement continues for a longer portion of the practice period than is the case for evolutionary learning.

The main difference between the continuous and discrete forms of revolutionary learning is that in the discrete form there is no intermediate method; the worker uses either one set of elements or another. The MARBLES task (see appendix A) is typical of the continuous change form; the subject gradually reduces the precision of placement of marbles in the bowl and simultaneously reduces the movement distance as the marbles begin to be tossed into the bowl rather than placed there. The SPOFF task is typical of the discrete form. Subjects must either reach into the bin to drop the spacers or they can toss them in through a hole in the front of the bin - there is no intermediate form so the transition is sudden and clear cut.

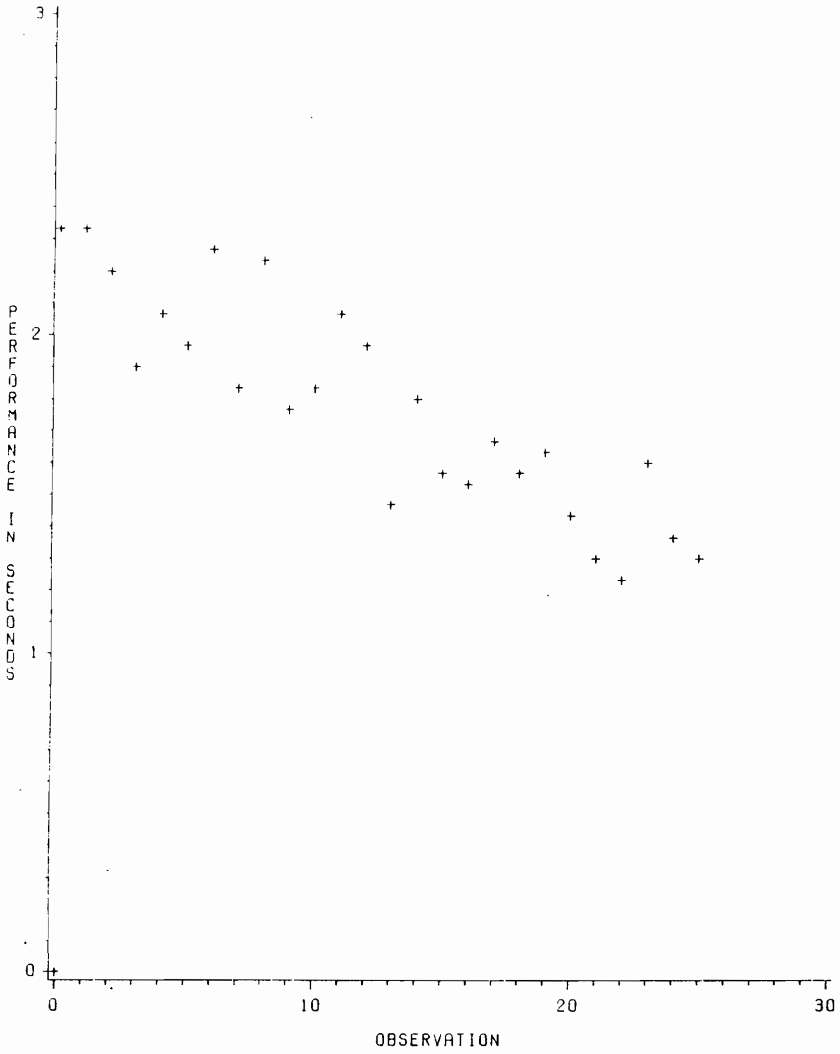
Consistency of learning method is analyzed in Table 4. One of the objectives of this research was to determine the utility of early per-

Figure 1. Evolutionary learning pattern.



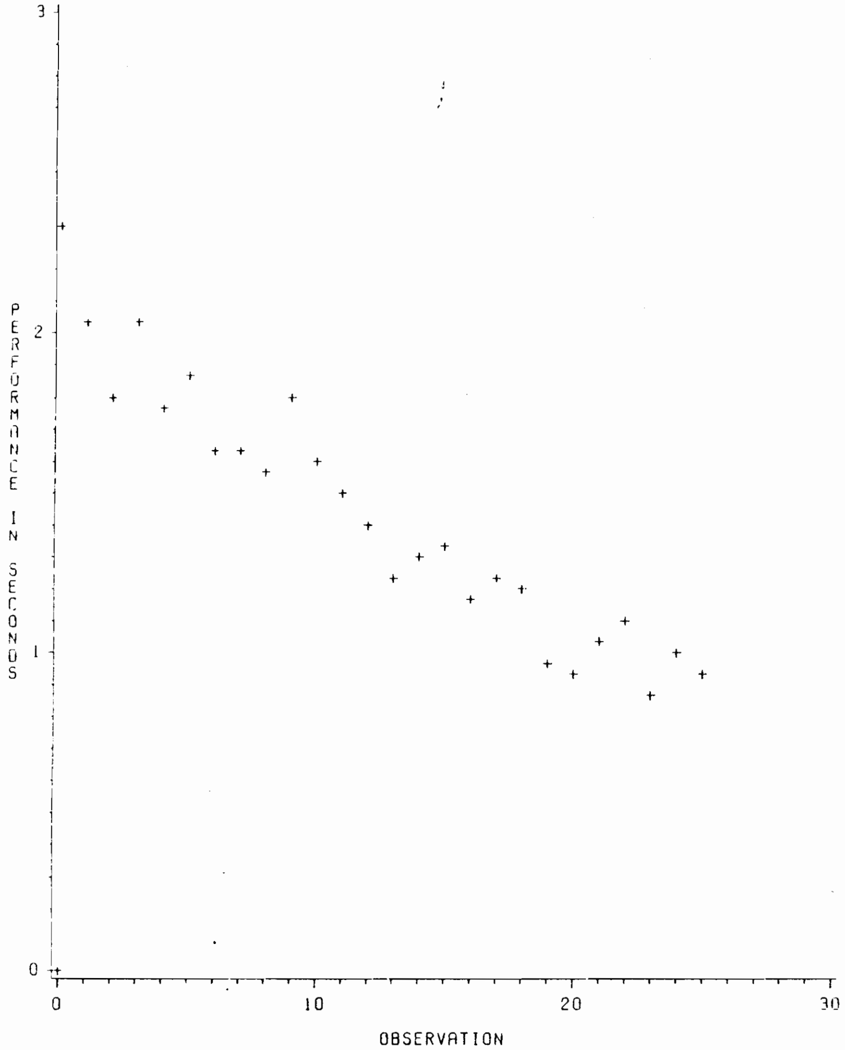
formance in predicting final learned performance. The improvement associated with a change in tactics is uniquely related to the nature of the change; performance immediately after a change in method may vary greatly from performance immediately before the change. Prediction of the effectiveness of a change in method does not appear to be simple, and may

Figure 2. Revolutionary learning pattern with discrete change.



in fact be impossible. If the prediction of improvement in performance immediately after the change cannot be made based on performance immediately before the change, it was felt that prediction of final learned performance would be unnecessarily complicated by using early performance on tasks learned in a revolutionary method as a model input.

Figure 3. Revolutionary learning pattern with continuous change.



There are essentially two methods for eliminating revolutionary tests from use as model inputs: observe a subject while learning a task and do not use tasks that are learned in a revolutionary manner; or, categorize tasks and use only tasks in the evolutionary group. One of the objectives of this study was to determine the utility of early per-

Table 3. Expected and observed learning method in pilot study.

```
      EXPECTED METHOD     OBSERVED METHOD

             FREQUENCY|
              PERCENT | EVOLUT | REVOLUT|  TOTAL
             ---------+--------+--------+
         EVOLUTIONARY |     69 |     18 |     87
           LEARNING   |  56.10 |  14.63 |  70.73
             ---------+--------+--------+
        REVOLUTIONARY |     10 |     26 |     36
          LEARNING    |   8.13 |  21.14 |  29.27
             ---------+--------+--------+
             TOTAL          79       44      123
                         64.23    35.77   100.00


               STATISTICS FOR TABLE OF
               EXPECTED AND OBSERVED LEARNING METHOD

     STATISTIC                     DF      VALUE        PROB
     ------------------------------------------------------
     CHI-SQUARE                     1     29.431       0.000

     SAMPLE SIZE = 123
```

formance in predicting fully learned performance so it is counter productive to study the complete learning cycle before deciding whether to use the results of the early learning performance. In order to test the consistency of learning method 5 able-bodied subjects and 3 disabled subjects were trained on a group of tasks that were categorized as to learning method. Table 4 illustrates the high level of predictability of the methods of learning observed in the tasks being evaluated for use as model inputs and for model validation.

Unlike previous investigators I found movement times to improve under either of two conditions. During revolutionary learning when either able-bodied or disabled subjects switched to a work method using shorter motion distances the time to make the move was reduced. This typically occurred when the subject found that a part could be safely tossed into a container rather than by positioning the hand directly over the target and dropping the part into the container. The distance traveled by the hand when tossing an object into a container is reduced, the level of precision for a tossed object is the same as for a dropped object therefore the time savings can reasonably be assigned to the movement time of the task. This type of movement related improvement was anticipated.

Movement time reduction was unexpectedly observed in disabled subjects with large muscle deterioration. In all able-bodied and most disabled subjects under evolutionary learning conditions and during revolutionary learning when the change in pattern involved the precision of part placement most of the learned improvement was observed to occur in the manipulation portion of the tasks. However, when disabled subjects with limited large muscle strength attempted a hand movement from one location in the work space to another they demonstrated a unique performance improvement during the ballistic portion of the maneuver. In early attempts these very weak subjects would spend an excessive portion of trial time getting their hands into position for the manipulation; typically, they approach the target with a series of hand jerks. With practice they reduce the number of sequential repositionings necessary, thus reducing movement time.

Discussion of experiment 1

Efforts to isolate single element performances on videotape proved unsuccessful. The individual moves and their successive manipulations were found to be inseparable in any meaningful manner. This is in basic agreement with Fitts' Law which limits the area of consideration to pairs of moves and their associated manipulations. As in previous work the moves were found to involve several accelerations and decelerations between the time on action initiation and completion. Subjects could be observed to move a hand rapidly toward a target and then to slow the ballistic velocity as they approached a crucial point in the action or to complete the movement portion and then to hesitate as they performed the manipulation. Completion times were observed to remain constant whether subjects moved rapidly to a target and slowly manipulated it or, alternatively exhibited a slow move toward the target and then rapidly manipulated it. For any stage of training on a specific task mean time to perform remained relatively constant while element times fluctuated greatly.

One finding, apparently not previously reported in the literature, was that for very weak subjects, the normal acceleration-deceleration motion series degenerated into a sequence of starts and stops. This altered the normally smooth velocity changes into a set of jerks toward the target. With practice the weak muscled subjects learned to reach the target with fewer hand repositionings making them virtually the only subjects to show learned improvement during the movement portion of the tasks.

Pairs of moves and manipulations were reliably measurable. The combination of a move and the successive manipulation were found to be relatively stable for an individual subject at a given level of training. This is in theoretical agreement with Fitts' Law which states that performance time is a function of movement distance AND manipulation precision. The two factors of distance and precision cannot apparently be separated.

Although a pairwise measurement of elements was found possible it was not ideal. Most tasks could not be measured from the beginning of a move through the completion of the following manipulation. Many of the tasks involved manipulations that either had no clear ending point or which occurred at a location where the ending point could not be directly observed. Hence, for most tasks it was necessary to use way points along the motion path as time measurement points. Consider the simple task of moving marbles from one bowl to another - at the time the marble is successfully grasped the finger tips are obscured by the bowl. To measure a reach/grasp combination it was necessary to use some way point such as the finger rising above the bowl lip as the end point of the action. This inclusion of move-grasp-withdrawal in the measurement unit produced a bias in performance times.

The third effort to measure short duration work element combinations involved groups of four elements considered as a work unit. This proved very successful. Using groups of four elements allowed simple work patterns to be measured as a reach-get-move-place combination. These 4 element groups could be repeated in a cyclical fashion allowing the measurement at any one way point in the cycle to be used for the timing without biasing the results. By beginning the timing of the task at some way point in the first (or any) cycle and recording the time at which that way point was passed during each successive cycle meaningful work times could be measured.

The use of 4 element tasks had two practical benefits. Most of the AMI and Workability tests consist of 4 work elements each so that their use for this research did not require a lengthy validation phase. And secondly, data collection in future research using 4 element tasks should be easier to automate as only one sensor need be monitored, simple recording of time between activations should suffice, and no observer intervention is necessary during data collection.

The pilot study demonstrated that although there are two subpatterns for each group of subjects, on the whole both the able-bodied and disabled groups exhibited the same classic learning patterns. On 103 learning tests, 35 of which were performed by one of 5 able-bodied subjects and 68 of which were performed by one of 3 disabled subjects, the mean performance times and standard deviations consistently diminished with practice (see Table 3).

The tasks producing a revolutionary learning demonstrated one possible explanation for the step-wise learning patterns hypothesized by some researchers. In the revolutionary pattern at some point the subject

Table 4. Effect of practice on mean and standard deviation.

GROUP	STATISTIC	BEFORE PRACTICE	AFTER PRACTICE	Z	PROB
35 ABLE-BODIED	MEANS	40.74	31.99	3.53	0.000
	SD	6.71	4.23		
68 DISABLED	MEANS	64.72	57.52	2.60	0.005
	SD	13.00	10.23		

changed strategies producing a rapid, step-like improvement in performance. The sudden change in performance was accompanied with a proportionate change in the Modapts description of the action sequence.

In addition to the work element explanation of this sudden change in performance there is at least one other view, compatible with the Modapts analysis, that explains the sudden change in performance. Heyde developed Modapts, at least in part, because he believed that the most efficient work method should always involve the use of the least extensive body involvement. If a finger can perform an action then an arm should not be used as it involves both more energy usage and more acceleration time. Each of the observed revolutionary performance changes involved either a reduction in work precision (i.e., a reduction from excess precision to a level just sufficient to produce acceptable results) or a reduction in excess body part involvement (i.e., use of forearm motion to do what had previously been done by whole arm motion). Most of the revolutionary changes involved a reduction in body involvement in the task, this may be a physiological response.

Results of the first experiment were used to develop tests for the remainder of this research. Four element cyclical tasks were developed. Only tasks which generally exhibited evolutionary learning were used for predictions; although, tasks which induced revolutionary learning were included in the validation set.

EXPERIMENT 2: TEST DEVELOPMENT

Ward (1988) used all of the 29 AMI tests involving manual dexterity. This subset of the AMI battery was used, even though some of the tests were redundant, because they were available and validated. The mathematical procedure used to estimate the work element means from this set required only 12 tests but the additional data were used to insure sufficient information for model prediction and to avoid problems associated with singular matrices. For the current study it was decided to identify a minimum number of tests so as to reduce the effort required of the subjects and to allow sufficient repetition of the selected tests so as to assure the complete learning of each test and validation task.

As discussed above tests were designed to use previously validated tasks. Other considerations in test development were availablity of test materials and familiarity of subjects with test hardware. Where possible, tests were designed to use common household objects. This reduced equipment costs, assured the availability of test equipment at all test locations, and reduced subject intimidation.

The selected tests were administered to both able-bodied and disabled subjects. Results were timed for algebraic computations and videotaped for frame-by-frame analysis to verify the mathematical calculations.

Compatibility with the Worker Profile Model required the tests be selected to form a nonsingular matrix. For the A matrix to be usable it not only needed to be invertable but also required a high level of robustness. Simple selection of tests assured the algebraic utility of the set but the tendency of human subjects to err required a more empirical approach to select a robust test set. Individual values of the T vector were increased and decreased by one standard deviation to determine the effect on the calculated values for WP. This resulted in the elimination of tests which were overly variable in performance and resulted in a more stable Worker Profile.

For complete description of the tasks used for testing and validation see Appendix A.

Analysis of experiment 2

The primary goal of experiment 2 was to develop a set of equations (tests) which could be used to calculate the 12 unknown element mean performance times. The equations therefore formed an invertable matrix. The nonsingular nature of the matrix of tests was used as one check on the adequacy of the test battery. Consistency of performance (i.e., the repetition of the same sequence of work elements on repeated trials with relatively noise free performance) is also important to a successful test battery.

One measure of consistency of performance is the smoothness of the learning process (i.e., is the learning evolutionary or revolutionary in nature?) It was decided to test a group of subjects on a set of tasks to determine if some tasks are consistently learned in an evolutionary manner. Each subject was trained on each task and method of learning was categorized as either evolutionary or revolutionary. The results were tested with a Chi square method. The results show that a task is consistently learned by one pattern or the other. Only tasks that were consistently learned in an evolutionary method were given further consideration for use as model inputs; however, validation tasks were selected from both groups of tasks.

Seventeen candidate tests (each of which was generally learned in an evolutionary style) were evaluated and compared. From the set of 17 tests there were 24 nonsingular subsets of 12 tests each. From this set of 24 possible test configurations one was selected as most robust. The technique used to compare tests sets required one subject to practice all 17 tasks until improvement ceased then a worker profile was computed for each of the 24 test sets. A mean value was calculated for each of the 12 work elements in the Worker Profile. This mean worker profile was used as the norm and each test set was perturbated by recomputing the worker profile with each possible input time value increased and decreased by one standard deviation. This generated 24 possible worker profiles for

Table 5. Expected and observed learning styles main study.

```
EXPECTED STYLE  OBSERVED LEARNING STYLE

   FREQUENCY   |
    PERCENT    | EVOLUT  | REVOLUT|  TOTAL
     ---------+--------+--------+
  EVOLUTIONARY |    151 |     41 |    192
   LEARNING    |  47.19 |  12.81 |  60.00
     ---------+--------+--------+
REVOLUTIONARY  |     34 |     94 |    128
   LEARNING    |  10.63 |  29.38 |  40.00
     ---------+--------+--------+
     TOTAL         185      135      320
                 57.81    42.19   100.00


      STATISTICS FOR TABLE OF EXPECTED AND OBSERVED STYLE

STATISTIC                     DF      VALUE        PROB
-------------------------------------------------------
CHI-SQUARE                     1     85.419       0.000

SAMPLE SIZE = 320
```

each test set. A cumulative Root Mean Square as determined for the deviation of all 24 profiles for each test set. The test set with the smallest cumulative perturbation effect was selected as the most robust for use in the remainder of this research.

Discussion of experiment 2

In previous work (Ward, 1988) it was observed that if a test set is selected without regard to its insensitivity to small measurement errors, those errors can cause the resulting worker profile to vary erratically. One solution to the problem of overly sensitive testing is to use a forcing function to desensitize the model. This shaping improves generalizeability of the model for able-bodied workers at a small cost in sensitivity on tasks similar to those used to generate the model parameters. However, the same shaping functions reduce the sensitivity of the model to the uniqueness of disabled workers. Selecting a test set based on robustness in the face of input perturbations was used as an alternative to the previously attempted shaping functions.

EXPERIMENT 3: BASE LINE STUDY ON ABLE-BODIED SUBJECTS

A group of 10 able-bodied student subjects were used to test and validate the model. Student volunteers were selected to match the disabled group for age and gender. Subjects were all students at Virginia Tech, and each was paid $5.00 per hour for participating in the study. Half of the subjects were male, and half were female.

Each subject attended three sessions in the laboratory. Each subject's first session lasted one hour during which the subject was tested on each of 20 tasks. Each task was repeated three times, and performance was recorded on cycle 1 through cycle 6 of the first trial and during the last 6 cycles of the third trial.

Twelve of the tasks had previously been identified as model inputs and the other 8 tasks were used to validate the model. Input tasks were

Table 6. Able-bodied subjects summary table.

Pearson correlation coefficients (R) / standard error (s.e.)

PREDICTOR		ACTUAL TASK PERFORMANCE FOR: ALL TASKS	LONG DURATION	SHORT DURATION	BUILD ONLY	CHLN ONLY
EARLY_MEAN	R =	0.88	0.96	0.10	0.89	0.31
PERFORMANCE	s.e. =	0.08	0.07	0.58	0.77	0.74
EARLY_BEST	R =	0.93	0.96	0.13	0.91	0.21
PERFORMANCE	s.e. =	0.05	0.08	0.51	0.73	0.65
LATE_MEAN	R =	0.91	0.96	0.15	0.87	0.28
PERFORMANCE	s.e. =	0.07	0.07	0.44	0.82	0.44
LATE_BEST	R =	0.93	0.96	0.04	0.84	-0.11
PERFORMANCE	s.e. =	0.09	0.07	0.34	0.64	2.76
MODAPTS	R =	0.94	0.94	0.27	****	****
	s.e. =	0.22	0.24	0.55	****	****

**** Indicates that for these tasks Modapts makes only one performance time estimate for all workers and thus explains none of the inter-worker variance.

all of the evolutionary learning type. Validation tasks were both evolutionary and revolutionary in nature. Model predictions were generated for each validation task for each of the 4 performance measures.

Analysis of experiment 3

The column labelled "ALL TASKS" in Table 6 compares the predictive power of the Action Set Worker Profile Model for each of the 4 experimental measures of performance with that of Modapts on each of 8 validation tasks. Performance data from the 12 input tasks was measured as early mean performance (EARLY_MEAN), early best performance (EARLY_BEST), after practice mean performance (LATE_MEAN), and best after practice performance (LATE_BEST). Predictions of performance on each of the 8 validation tasks was made based on each of the 4 performance measures for each of the subjects. The 8 validation task times were also estimated using the standard Modapts method. The subjects were each trained on the 8 validation tasks and performance was measured. Results show the Modapts prediction for all tasks performed by able-bodied subjects to be marginally superior to the predictions of the Action Set Worker Model.

The columns labelled "LONG DURATION" and "SHORT DURATION" in Table 6 analyze the model predictions on long and short duration tasks. Three of the validation tasks CHLN, CHOFF, and DOUT (see appendix A for details and descriptions of the tasks) were each of very short cycle duration. The other 5 validation tasks were of longer duration. Masud et. al. (1985) and Heyde (1983) have suggested that task cycle time and predetermined time standard element times are related in such a manner that below a certain level of task complexity element times are not constant. Models that are based on constant work element times are limited to certain ranges of cycle duration. Table 6 shows no significant differences between the predictive power of the Action Set model and of Modapts for ALL TASKS and for LONG DURATION tasks. None of the predictions is acceptablly accurate on short cycle tasks.

The two leftmost columns in Table 6 demonstrate the model's accuracy on individual tasks. The BUILD task (see appendix A for details) is the longest duration and most complex of the laboratory tasks used in this study. Table 6 shows the models highly sensitive prediction of individual differences in performing the BUILD task. The Modapts prediction is that all able-bodied workers will perform this task in the same time; therefore, Modapts explains none of the performance variance. The column labelled "CHLN ONLY" in Table 6 shows the insensitivity of the model in predicting performance on the CHLN task (the shortest task in the validation set).

Discussion of Experiment 3

The model demonstrated a remarkablely high degree of sensitivity for the individual differences in able-bodied subjects given the traditional predetermined time standard philosophy that all workers perform identical tasks in essentially the same amount of time. The model proved considerably better at predicting long duration tasks than for short duration tasks in general, and these results were equally valid for specific long and short duration tasks as they were for groups of tasks.

EXPERIMENT 4: TEST AND VALIDATE WITH A GROUP OF DISABLED WORKERS

Six physically disabled people were tested with 12 tasks each; 4 measures of performance (early mean, early best, late mean, and late best)

Table 7. Disabled subjects summary table.

Pearson correlation coefficients (R) / standard error (s.e.)

PREDICTOR	ACTUAL TASK PERFORMANCE FOR: ALL TASKS	LONG DURATION	SHORT DURATION	BUILD ONLY	CHLN ONLY
EARLY_MEAN PERFORMANCE	R = 0.74	0.95	0.34	0.95	0.45
	s.e. = 0.76	0.64	0.98	0.54	0.37
EARLY_BEST PERFORMANCE	R = 0.69	0.95	0.23	0.95	0.23
	s.e. = 0.16	0.11	0.67	0.21	0.66
LATE_MEAN PERFORMANCE	R = 0.80	0.97	0.49	0.99	0.57
	s.e. = 0.19	0.16	0.74	0.23	0.24
LATE_BEST PERFORMANCE	R = 0.70	0.96	0.69	0.96	0.94
	s.e. = 0.30	0.26	0.84	0.33	0.15
MODAPTS	R = 0.83	0.81	0.03	****	****
	s.e. = 0.63	0.55	0.90	****	****

**** Indicates that for these tasks Modapts makes only one performance time estimate for all workers and thus explains none of the inter-worker variance.

were made; performance was used as an input to the Action Set Worker Profile Model; and, model predictions on 8 validation tasks were compared to Modapts predictions.

Analysis of experiment 4

As was the case with able-bodied subjects the model was not significantly different than Modapts. Table 7 shows the model to predict a significant portion of individual difference in performance across all

Table 8. All subjects pooled for maximum subject diversity.

Pearson correlation coefficients (R) / standard error (s.e.)

		ACTUAL TASK PERFORMANCE FOR:				
PREDICTOR		ALL TASKS	LONG DURATION	SHORT DURATION	BUILD ONLY	CHLN ONLY
EARLY_MEAN	R =	0.79	0.94	0.56	0.97	0.69
PERFORMANCE	s.e. =	0.02	0.05	0.11	0.17	0.53
EARLY_BEST	R =	0.76	0.92	0.43	0.95	0.47
PERFORMANCE	s.e. =	0.02	0.04	0.14	0.10	0.33
LATE_MEAN	R =	0.84	0.97	0.65	0.99	0.73
PERFORMANCE	s.e. =	0.02	0.05	0.25	0.09	0.35
LATE_BEST	R =	0.77	0.95	0.74	0.98	0.91
PERFORMANCE	s.e. =	0.03	0.08	0.23	0.08	0.14
MODAPTS	R =	0.72	0.70	0.07	****	****
	s.e. =	0.52	0.45	0.63	****	****

**** Indicates that for these tasks Modapts makes only one performance time estimate for all workers and thus explains none of the inter-worker variance.

tasks. The preportion of individual variability explained by the model for the disabled is not significantly less than was the case with able-bodied subjects. As was the case in Table 6 with the able-bodied subjects Table 7 shows late performance predictors to be no more accurate than early performance measures.

The column labelled "LONG DURATION" Table 7 shows that for long duration tasks the model was about as good for the disabled subjects as it was for the able-bodied (Table 6). Modapts proves no better at predicting disabled workers' performance for long duration tasks than it did for all tasks. On short duration tasks the model again proves to be significantly better than Modapts.

A comparison of Tables 6 and 7 shows that the power of the model holds up for specific long and short duration tasks to a greater extent for the disabled worker group than it did for the able-bodied group. The model was developed to characterize the individual differences in workers and seems to gain power in proportion to the diversity of the worker pool. To test this proposition the entire set of subjects will be pooled for analysis in Table 8.

Table 8 pools the data for the 2 groups of subjects pooled. On the more diverse combined group of all subjects the individual variability explained by the model tends to be intermediate between the results of the 2 groups analyzed separately. The Modapts predictions for the combined groups is worse than the separate predictions. The model works as well for long duration task prediction for the more diverse group as it did for the separate groups; again, Modapts is significantly worse for long tasks on the combined results than it was for either individual group. The added diversity of the combined group makes the model's 4 measures all significant predictors on the short duration tasks; again Modapts power is degraded by the added diversity of the combined groups. The left-hand columns of Table 8 shows that the model's power on individual long and short duration tasks reflects its power on groups of long and short duration jobs.

Discussion of Experiment 4

The most important finding in this experiment is that the early predictors are as powerful and dependable as are the predictors based on extensive practice. The early predictors are the result of 2 to 3 minutes of effort and they are as good a predictor of work element mean time for an individual as are the tests that require up to 5 hours of practice.

Unlike Modapts which is based on the notion that all workers are equal and interchangeable, the Action Set Worker Profile becomes increasingly sensitive as individual differences within the worker pool are increased. The predetermined time systems were introduced as a labor saving tool to replace the early, and more cumbersome, work design tools such as MTM. By increasing the element size and reducing the number of options available to the industrial engineer MTM2, Most, and Modapts allowed the work designer to quickly determine approximately the time requirement for a job at a modest loss in accuracy. With the availability of the computer to perform the tedious accounting it is no longer impossible to accurately represent the individual worker in the modelling process. The above tables demonstrate the increase in accuracy possible when using a true profile of the individual in performance predictions. The relative advantage of the model increases with increasing diversity in the worker population and the advantage, even for the able-bodied population, which is the most homogenous group tested, when the model is tuned to the approximate complexity of the task to be estimated (see Table 6 LONG DURATION and BUILD ONLY tasks). The Action Set Worker Profile

Model shows a clear superiority to Modapts when there is diversity in the work force and when the model is tuned to actual job complexity.

EXPERIMENT 5: VALIDATION OF WORKER PROFILE IN WORKSHOP

The modeling technique was validated by comparing predicted work times to actual on-the-job performances. The subjects were drawn from the worker population at a local sheltered workshop; most of whom have been cross trained on several jobs. Actual performance of 3 disabled subjects was compared to Modapts and Action Set Worker Profile predictions of performance. One job was selected because all 3 subjects have regularly performed this cardboard assembly task for several months before this study began. The task consists of breaking a precut cardboard form from a sheet of forms and folding it into shape. For complete description see appendix B. The Modapts description calls for 78 mods per cycle plus 10 additional mods per fifth cycle or a total of 80 mods per assembly. By the standard work conversion factor this would be 11.4 seconds per assembly or 315 assemblies per hour under workplace conditions.

Analysis of experiment 5

In experiments 3 and 4 both testing and validation were done under laboratory conditions. Heyde (1983) has stated that lab performance

Table 9. Comparison of model prediction to actual job performance.

SUBJECT 1

ACTUAL PRODUCTION = 29 PER HOUR SD = 5.6

80% CONFIDENCE INTERVAL

	LAB	WORKPLACE
EARLY_MEAN PREDICTION	39 - 53	25 - 39
EARLY_BEST PREDICTION	41 - 55	27 - 41
LATE_MEAN PREDICTION	36 - 50	23 - 37
LATE_BEST PREDICTION	41 - 55	27 - 41
MODAPTS PREDICTION	443 - 457	318 - 308

SUBJECT 2

ACTUAL PRODUCTION = 85 SD = 13.7

80% CONFIDENCE INTERVAL

	LAB	WORKPLACE
EARLY_MEAN PREDICTION	85 - 120	54 - 89
EARLY_BEST PREDICTION	98 - 133	64 - 99
LATE_MEAN PREDICTION	91 - 126	59 - 94
LATE_BEST PREDICTION	105 - 140	68 - 103
MODAPTS PREDICTION	433 - 468	298 - 333

SUBJECT 3

ACTUAL PRODUCTION = 51 SD = 11.9

80% CONFIDENCE INTERVAL

	LAB	WORKPLACE
EARLY_MEAN PREDICTION	52 - 82	32 - 62
EARLY_BEST PREDICTION	61 - 91	38 - 68
LATE_MEAN PREDICTION	57 - 87	35 - 65
LATE_BEST PREDICTION	66 - 96	42 - 72
MODAPTS PREDICTION	435 - 465	300 - 330

should be multiplied by 0.7 to convert it to workplace values. Table 9 shows actual recorded workshop production for each of 3 subjects and the corresponding predictions generated by the model under each of the 4 input measurement conditions and the Modapts estimate for able-bodied workers.

Discussion of Experiment 5

None of the 3 subjects is capable of more than about 25% of normal able-bodied production. Modapts makes no allowance for the differences between these individuals and the average worker. Although many workshops are currently using predetermined time systems to assign piece work pay scales to jobs none are currently using the systems to optimize work assignments. The worker profile approach, on the other hand, allows the workers to be rated and ranked on each job.

The LAB vs. WORKPLACE comparison shows that as in Heyde (1983) where able-bodied workers were shown to work more rapidly under lab/testing conditions than they did in the workplace these disabled subjects also adjusted their work speed according to the environment in which they were performing. Only one of the LAB condition estimates of production falls within an 80% confidence interval of actual observed performance. All of the Worker Profile workplace adjusted predictions fall within the 80% confidence interval although some measures are more accurate than others.

SUMMARY OF DISSERTATION RESEARCH

Two learning patterns were observed in both the able-bodied and the disabled subjects. The evolutionary pattern involves the continuous smooth improvement of a single work method with practice over time. The revolutionary method demonstrated a change in the sequence of work elements used to perform the task as a result of a tactical change during practice. The change in work elements used involved either a reduction in precision where originally excess precision was used or a reduction in movement distance. Some very weak disabled subjects also showed a performance improvement by reducing the number of ballistic moves required to reach a target.

Learning patterns are consistent for individual tasks. Most subjects use the same learning method on a given task making it possible to categorize tasks as either evolutionary or revolutionary. Different revolutionary tasks show different amounts of improvement at the time of the tactical change in work method making early performance of these tasks poor predictors of final learned performance time. All tasks used as Action Set Worker Profile Model inputs were selected from the set of tasks generally learned in an evolutionary manner.

Four performance measures were tested as model inputs. Early mean performance (EARLY_MEAN) was the average of 12 early cycles of the task including the first 6 cycles attempted and an additional 6 cycles sampled during the subjects first exposure to a task. Early minimum performance (EARLY_BEST) was the best single cycle of the 12 included in the early minimum. Late mean performance (LATE_MEAN) was the average of 12 cycles from the subjects final session with sampling beginning after a short practice period.

Late performance on test tasks was a better predictor of validation task performances than early performance of test tasks. This may in part been a result of some subjects using revolutionary learning methods on some test tasks resulting in degraded estimation of work element times based on early performance. It was also noted that with practice errors became less frequent, less serious, and less disruptive resulting in fewer error induced delays being included in late performance measures than were included in early performance measures.

Long duration tasks were predicted more reliably by the model than were short duration tasks. This is in agreement with the opinions expressed in Masud et. al. (1985) and Heyde (1983). With short duration, low complexity tasks workers seem to develop a rhythm not demonstrated in more complex tasks.

The case of able-bodied subjects performing short duration tasks was the only condition in which neither Modapts nor the Worker Profile approach proved effective. This is of course also the case where prediction would be of minimum practical benefit: worker diversity is minimal and total time and effort are trivial as compared to a complete job. Modapts exhibits maximum power in situations where worker diversity is minimized and task differences are large. The Action Set Worker Profile Model is most powerful when human differences are large and task differences are moderate to small.

The model's superiority to Modapts increased when greater individual difference was exhibited by the subjects. Modapts was marginally superior only in the case of minimum individual difference between subjects and maximum task differences (i.e., able-bodied subjects with all tasks pooled - see Table 6). In all other cases where a prediction was possible the Action Set Worker Profile Model was superior to Modapts.

The model was consistently better than the predetermined time standard for the disabled group alone and for the pooled subject set on the pooled (all) tasks, the general long and short duration tasks, and the specific long and short duration tasks.

FUTURE WORK

SIMULTANEOUS OPERATIONS OF BOTH HANDS.

Very little work has been done on the problem of total job performance time relative to the time required for each hand to perform its portion of the task separately. One of the basic premises of Modapts is that two handed work requires a time greater than or equal to the time required by the more burdened of the two hands and that total performance time is less than the sum of the time required to perform the two halves of the job sequentially.

The Modapts assumption is that while the more burdened hand is performing the less burdened hand can be at least positioned to begin work when the worker's attention is released from the active hand. In the case of low precision work the two hands can actually be used simultaneously with no loss in performance. Designing work for the two hands to perform simultaneously is at best an art - it seems to be the area where experts are most likely to disagree on standards.

For the disabled the assumptions seem to be at least overly optimistic and possibly completely wrong. A number of subjects in the Human Assessment Lab have required time nearly double that of the more burdened hand time to perform two handed operations. The difficulty appears to lie in both the disengaging of attention from the more burdened hand and in interference by the alternate hand as it is readied for its next task.

USE FOR SELECTION OF COMPUTER INPUT DEVICES.

The relative proficiency in performing work elements as determined by the Worker Profile Model should aid in selection of computer input devices. It should be a relatively simple procedure to associate work element requirements to the use of a particular device.

The greater the similarity of the test set to the final predicted application the smaller the demand for test robustness and generalizeability. Careful selection of tests to duplicate the target application would probably be beneficial; although the use of these test results to generate a model for prediction of other work performance would probably be limited.

INDEPENDENCE OF ELEMENTS?

Heyde has stated repeatedly that Modapts work elements are completely dependent on one another and that there is no independence of work performance times. It is his belief that the measurement of any one element allows the simple, direct calculation of all work element performance times. He has apparently confused the ratios of the worker population's mean element performance times for the actual relative performance times of individuals. While for a large enough sample size the mean time to perform a P2 action is twice the time required to perform the M1 and equal to the time required to perform an M2 move and half the time required for an M4 this ratio does not appear binding on the individual worker.

Although there does not seem to be a complete lack of independence between work elements, neither can it be said that the work elements are completely independent of one another. In this study it was consistently found that M1 and G1 times are approximately equal as are P0 and G0 times. For the disabled the ratios of move times and complex manipulations are much less closely related. Individuals with large muscle deterioration or upper arm accident damage are often relatively more proficient at complex manipulations than at long moves. People with nerve degeneration, joint damage, or central nervous system based disabilities exhibit poor fine motor coordination but can often move the hands about the workplace with ease.

Lack of the necessary information on the independence of the work elements has limited modeling efforts. This lack of knowledge has to effects; it prevent calculation of variances; and, it increases the apparent dimensionality of the problem. With some investigation of the relationships between work element performance times a dimensional reduction of the test space should be possible. A reduction in the dimensionality of the problem would allow a proportional reduction in the future work number of tests required and the amount of time required to generate the worker profile.

One approach to this might be to calculate move ratios and manipulation ratios for each individual. Heyde assumes the move ratios are always 1 to 2 to 3 to 4 which works well enough for able-bodied workers but does not account for the qualitative differences seen in some disabled workers between the M1 and M2 finger/hand moves and the M3 and M4 forearm/whole-arm moves needed for the M3 and M4 work elements. The work element ratios between high precision and low precision manipulations also appears to related to type of disability.

If the work element ratios could be adjusted to the individual it would then be possible to calculate a single multiplicative factor to compute actual performance on any job.

DIVERSITY OF STRATEGIES TO ACCOMPLISH SAME TASK.

This study has touched on the difference in learning patterns between tasks where a single performance strategy is used from the onset of practice until final proficiency is achieved and the learning pattern of tasks where the work method used is modified during practice. Disabled workers on the job often find that the standard work method is not ideal for them and use a modified method to achieve their own optimal performance. Nothing in the work done so far addresses how to predict when there might be a better method for an individual. The worker profile approach does allow known methods of job performance to be compared but it does not seek or identify new or unknown methods.

NETWORK MODEL OF VARIOUS APPROACHES.

One approach to systematically searching out alternative methods would be the use of a network model of the methods for performing specific tasks. This would allow each known method to be compared and encourage the combination of diverse methods in every possible combination in a form easily explored using standard operations research methods. In effect all possible routes from a given start state to a desired end state could be mapped and then for each tested worker the work element performance times could be assigned to network arcs and the work space could be searched for a minimum route.

ROBUSTNESS AND GENERALIZEABILITY

As mentioned above there seems to be a relationship between the Worker Profile focus to specific types of tasks and its generalizeability to other forms of work.

EXTRACTION OF ELEMENT VARIANCES

Although it had been hoped that Modapts element variances could be extracted from the tests used in this study that proved impractical. The use of successive single cycle performance times to drive the model produced results with variances approximating the mean performance times of the individual elements. It will be necessary to redesign the test procedure in order to generate usable variances.

A second problem related to the calculation of variances is the lack of independence in work element order. Because work element order is always a sequence of alternating moves and manipulations the mean times can be shifted in opposite directions without loss of prediction of job times. In spite of the fact that mean times can be biased by the consistent adding of a constant to all moves and the subtraction of the same constant from all of the manipulations, the same does not hold for the variances.

One of two things must be done to make variance of work element calculations possible: reduce the dependence of the system (by reducing the dimensionality); or, find a method of calculating the individual, unbiased work elements.

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APPENDIX A. DESCRIPTION OF TASKS USED IN THIS RESEARCH.

CODE	MODAPTS	TEST NAME
BB	M3G3 M3P0	BB TRANSFER

Description:

Two 5 inch diameter glass bowls are placed 4 inches apart in front of the subject who is allowed to shift them on the no-skid work surface until they are comfortably placed. A distance of 4 inches between the bowls in maintained by the presence of a plastic spacer. The inside bottom of the bowls in covered with a pliable substance to prevent dropped objects from bouncing out of the bowl. Eleven steel BBs are place in the bowl on the subjects preferred side. The subject is instructed to move the BBs from the bowl in which they are contained to the other bowl using preferred hand only moving them one at a time. Timing begins when the subject drops the first BB into the empty bowl and ends with the dropping of the last BB. Ten complete cycles are timed.

CODE	MODAPTS	TEST NAME
BIGM	M3G1 M3P0	BIG MARBLE TRANSFER

Description:

Two 5 inch diameter glass bowls are placed 4 inches apart in front of the subject who is allowed to shift them on the no-skid work surface until they are comfortably placed. A distance of 4 inches between the bowls in maintained by the presence of a plastic spacer. The inside bottom of the bowls in covered with a pliable substance to prevent dropped objects from bouncing out of the bowl. Four large glass marbles (the size of ping-pong balls) are placed in the bowl on the subjects preferred side. The subject is instructed to move the marbles from the bowl in which they are contained to the other bowl using preferred hand only moving them one at a time. Timing begins when the subject drops the first marble into the empty bowl and ends with the dropping of the last marble. Timing cue is either the release of the first marble or the sound on it striking bottom of the bowl. Three complete cycles are timed.

CODE	MODAPTS	TEST NAME
CHLN	M3G0 M3P2	CHECKER LINE SLIDE

Description:

A pair of parallel lines are affixed to the table directly in front of the subject. The lines are 6 inches apart and perpendicular to the edge of the table. The subject can shift to the right or left to find a comfortable position. Eleven checkers are placed along the line to the subject's preferred side. The subject is instructed to slide the checkers one at a time, using the preferred hand only, from one line to the other. Checkers are to start and finish in contact with one of the lines. Control of the checkers is by simple touch in order to demonstrate the Modapts G0 element. Checker should be placed in contact with the finish line but need not be precisely placed for the Modapts P2 element. Timing begins when the subject has moved the first checker to the finish line, the timing cue is the breaking of contact between the subject's finger and the checker. Ten cycles are timed. If the task is to be repeated the start line and finish line designations can be reversed so that the checkers are moved in opposite directions on subsequent trials.

CODE	MODAPTS	TEST NAME
CHOFF	M2G0 M1P0	CHECKERS OFF BOARD

Description:

A checker board is placed on a table directly in front of the subject. Eight checkers are placed on the checker board squares along the edge of the board closest to the subject. The subject can shift the board on the table to find the most comfortable position. Using preferred hand only the subject slides the checkers off the board onto the table. Checkers are moved by sliding them with the simplest touch contact that the subject is capable of in order to exhibit the Modapts G0 element. Checkers should be allowed to remain where ever they fall on the table to exhibit the Modapts P0 element. Timing begins when contact is broken with the first checker to be moved off the board. Seven cycles are timed. This task can be used alternately with the CHON task which is used to replace the checkers on the board.

CODE	MODAPTS	TEST NAME
CHON	M2G1 M1P2	CHECKERS ONTO BOARD

Description:

A checker board is placed on a table directly in front of the subject. Eight checkers are placed on the table along the edge of the board closest to the subject. The subject can shift the board on the table to find the most comfortable position. Using preferred hand only the subject lifts the checkers onto the board placing one in each square along the edge of the board. Checkers are lifted with the simplest grasp that the subject is capable of in order to exhibit the Modapts G2 element. Checkers should be placed completely within a single square to exhibit the Modapts P2 element. Timing begins when contact is broken with the first checker to be lifted onto the board. Seven cycles are timed. This task can be used alternately with the CHOFF task which is used to remove the checkers from the board.

CODE	MODAPTS	TEST NAME
CHSTK	M4G1 M4P2	CHECKER STACK

Description:

Eight checkers are placed along a line perpendicular to the edge of a table to the preferred hand side of the subject. A mark is placed on a line perpendicular to the middle of the line of checkers at a distance of 12 inches from the checkers. The subject is allowed to move the seat to a comfortable location. Instructions are given to move the checkers one at a time using the preferred hand only to the mark, stacking the checkers on top of one another. The original placement of the checkers along the line should allow sufficient spacing between checkers so as to allow them to be lifted using the G1 element motion. Stacking should only be as orderly as needed to keep the checkers from falling over, this will utilize the Modapts P2 element. Timing begins when the first checker is placed on the mark. The timing cue is the release of the checker by the fingers. Timing continues for 7 cycles.

CODE	MODAPTS	TEST NAME
DIN	M3G1 M3P0	DOMINOS INTO TRAY

Description:

A row of 8 dominos is laid along a line perpendicular to the edge of a table. An ice cube tray is placed 6 inches from the dominos with the long edge of the ice cube tray parallel to the row of dominos and the short edge of the tray parallel to the edge of the table nearest the subject. The dominos on the subject's preferred side and the ice cube tray on the subject's nonpreferred side. The subject is allowed to locate the chair to find a comfortable work position. The subject is instructed to lift the dominos one at a time using only the preferred hand and to place one domino in each compartment of the tray. Dominos should originally be separated to allow them to be lifted with the simple grasp G1. Dominos should be dropped end first into the openings in the tray as with a P0 action.

CODE	MODAPTS	TEST NAME
DOUT	M1G1 M1P0	DOMINOS OUT OF TRAY

Description:

An ice cube tray is placed on the table directly in front of the subject. The long edge of the tray is perpendicular to the edge of the table. Eight dominos are placed in the ice cube compartments on the preferred hand side of the tray. The subject should be instructed to grasp one domino at a time by the exposed end of the domino and lift it just high enough to clear the edge of the tray and to then drop it any where outside of the tray. Original positioning of the dominos should be such that one end extends up from each ice cube compartment. The end of the tray can be tipped up to orient the dominos in the same direction so that none of them interfere with the lifting of any of the others. The dominos should be grasped with a simple G1 grip and dropped outside of the tray with a P0 release. Timing begins when the first domino is dropped and ends with the drop of the eighth domino for a total of 7 cycles.

CODE	MODAPTS	TEST NAME
FLIP	M1G1 J2 M1P2	PEG BOARD FLIP TEST

Description:

A small peg board with 1 1/2 inch long pegs is placed on the table in front of the subject. The subject can position it and stabilize it with the nonpreferred hand. Using the preferred hand only the pegs are extracted one at a time, turned end over end, and replaced into their respective holes. The spacing of the holes allows the pegs to grasped with the G1 Modapts motion. The shape of the pegs makes their replacement with the Modapts P2 possible. The short distance the pegs are moved necessitates the use of a Modapts juggle (J2) during this task. Timing begins when the first peg has been replaced. The timing cue is the release of the fingers from the peg. Seven cycles are timed.

CODE	MODAPTS	TEST NAME
GROM	M4G1 M4P2 X4	AMI GROMMETS TEST

Description:

The standard AMI grommets assembly task. Performed at the AMI assembly station using the AMI 10 bolt plate and a bin filled with rubber grommets. The parts bin is positioned high and to the nonpreferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Grommets are removed one at a time with the preferred hand only and pressed onto the bolts. Timing begins when the thumb is removed from the first grommet and continues for 9 cycles. The tight fit of the grommets on the bolts and the friction caused by the bolt's threading forces the subject to use the Modapts X4 element.

CODE	MODAPTS	TEST NAME
LOCK	M4G3 M4P5	AMI LOCK WASHER TEST

Description:

The standard AMI lock washers assembly task. Performed at the AMI assembly station using the AMI 10 bolt plate and a bin filled with lock washers. The parts bin is positioned high and to the nonpreferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Lock washers are removed from the bin one at a time with the preferred hand only and pressed onto the bolts. Timing begins with the release of the first lock washer and continues for 9 cycles. The timing cue is the release of the fingers from the washer. The small size of the lock washers and their tight fit over the bolts requires the most precise puts and gets to be used in this task (i.e., G3 and P5).

CODE	MODAPTS	TEST NAME
M	M2G1 M2P0	MARBLES TRANSFER

Description:

Two 5 inch diameter glass bowls are placed with their rims touching in front of the subject who is allowed to shift them on the no-skid work surface until they are comfortably placed. The inside bottom of the bowls in covered with a pliable substance to prevent dropped objects from bouncing out of the bowl. Eleven glass marbles are place in the bowl on the subjects preferred side. The subject is instructed to move the marbles from the bowl in which they are contained to the other bowl using preferred hand only moving them one at a time. Timing begins when the subject drops the first marble into the empty bowl and ends with the dropping of the last marble. Ten complete cycles are timed.

CODE	MODAPTS	TEST NAME
M2G0	M2G0	BOLT TAPPING

Description:

Using the AMI 10 bolt plate attached to the AMI assembly work station the subject sequentially touches the ends of the bolts. This produces a short move followed by a tap. This task is the only one in this study that uses a natural 2 element action. Begin timing at the removal of the finger from the top of any bolt and time for 10 cycles.

CODE	MODAPTS	TEST NAME
M3G0	M2G0 M2G0 M3G0	TAPE TAPPING

Description:

Three parallel lines at 6 inch intervals are affixed to the surface of a table. The lines are oriented so as to be perpendicular to the table's edge. The subject is instructed to tap the line on the preferred hand side, then to move the finger to the line in the center of the three, then to tap the line on the nonpreferred side, and finally to return the finger to the preferred hand line and to continue this pattern of taps. This is the only task in this study to use three pairs of Modapts elements per cycle.

CODE	MODAPTS	TEST NAME
NUTS	M4G3 M4P5	AMI HEX NUT TEST

Description:

The standard AMI nuts assembly task. Performed at the AMI assembly station using the AMI 10 bolt plate and a bin filled with nuts. The parts bin is positioned high and to the preferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Nuts are removed from the bin one at a time with the preferred hand only and started onto the bolts. Subjects are instructed to only start each nut onto a bolt, they are not to "crank it down" any further than is needed to keep it from falling off. Timing begins with the release of the first nut and continues for 9 cycles. The timing cue is the release of the fingers from the nut. The small size of the nuts and their threaded fit over the bolts requires the most precise puts and gets to be used in this task (i.e., G3 and P5).

CODE	MODAPTS	TEST NAME
PP	M3G1 M3P0	PING-PONG TRANSFER

Description:

Two 5 inch diameter glass bowls are placed 4 inches apart in front of the subject who is allowed to shift them on the no-skid work surface until they are comfortably placed. A distance of 4 inches between the bowls in maintained by the presence of a plastic spacer. The inside bottom of the bowls in covered with a pliable substance to prevent dropped objects from bouncing out of the bowl. Four ping-pong balls are placed in the bowl on the subjects preferred side. The subject is instructed to move the balls from the bowl in which they are contained to the other bowl using preferred hand only moving them one at a time. Timing begins when the subject drops the first ball into the empty bowl and ends with the dropping of the last ball. Timing cue is either the release of the first ball or the sound of it striking the bottom of the bowl. Three complete cycles are timed.

CODE	MODAPTS	TEST NAME
SPOFF	M3G1 M3P0	SPACERS OFF BOLTS

Description:

Spacers are removed from bolts and replaced in their bin. Performed at the AMI assembly station using the AMI 10 bolt plate with spacer on each bolt. The parts bin is positioned high and to the preferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Spacers are removed from the bolts one at a time with the preferred hand only and replaced in their proper bin. Timing begins when the first spacer is tossed into its bin and continues for 9 complete cycles. Timing cue can be either the release of the spacer or the sound of it landing in the bin.

CODE	MODAPTS	TEST NAME

SPON	M4G1 M4P2	AMI SPACERS TEST

Description:

The standard AMI spacer assembly task. Performed at the AMI assembly station using the AMI 10 bolt plate and a bin filled with spacers. The parts bin is positioned high and to the preferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Spacers are removed from the bin one at a time with the preferred hand only and placed onto the bolts. Subjects are instructed to release the spacer as soon as it is securely over the end of the bolt. Timing begins with the release of the first spacer and continues for 9 cycles. The timing cue is the release of the fingers from the spacer or the sound of the spacer falling into place.

CODE	MODAPTS	TEST NAME
WOFF	M3G1 M3P0	FLAT WASHERS OFF BOLTS

Description:

Washers are removed from bolts and replaced in their bin. Performed at the AMI assembly station using the AMI 10 bolt plate with a flat washer on each bolt. The parts bin is positioned high and to the preferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Washers are removed from the bolts one at a time with the preferred hand only and replaced in their proper bin. Timing begins when the first washer is tossed into its bin and continues for 9 complete cycles. Timing cue can be either the release of the washer or the sound of it landing in the bin.

CODE	MODAPTS	TEST NAME
WON	M4G1 M4P2	AMI FLAT WASHERS TEST

Description:

The standard AMI washer assembly task. Performed at the AMI assembly station using the AMI 10 bolt plate and a bin filled with spacers. The parts bin is positioned high and to the preferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. Washers are removed from the bin one at a time with the preferred hand only and placed onto the bolts. Subjects are instructed to release the washer as soon as it is securely over the end of the bolt. Timing begins with the release of the first washer and continues for 9 cycles. The timing cue is the release of the fingers from the washer or the sound of the washer falling into place.

CODE	MODAPTS	TEST NAME

BUILD M4G1 M4P2 M4G1 M4P2 M4G3 M4P5 ASSEMBLY BUILDING TEST

Description:

The building task is the most complex laboratory task used in this research. Performed at the AMI assembly station using the AMI 10 bolt plate and 3 bins filled with spacers, flat washers, and nuts. The parts bins is positioned high and to the preferred side of the subject. A 10 inch square plate is attached to the work station directly in front of the subject. The plate has 2 rows of 5 bolts each oriented vertically on its surface. The subject is allowed to adjust the location of the work station and seat to obtain a comfortable work position. The subject is instructed to remove one spacer from the spacer bin and place it on a bolt. The spacer should be lowered only to the point where it is securely over the end of the bolt and then released. A washer is then extracted from the washer bin and placed over the top of the same bolt that the spacer was placed on. Each cycle is completed by attaching a nut to the same bolt which has just received a spacer and washer. As in the NUTS task the nut should only be turned as far onto the bolt's threading as is required to keep it from falling off. Timing begins when the first nut is released and continues for 9 complete cycles.

APPENDIX B. EXPERIMENT 5 VALIDATION TASK PERFORMED BY TRAINED WORKERS.

The validation task performed by 3 trained disabled workers at the workshop was a container assembly operation. The worker reached to a stack of perforated cardboard sheets and pulled off one precut box. The flat piece was moved to a location infront of the worker where the front edge was bent up until it was perpendicular to the base. One end flap was the folded back and another flap was pulled forward so that they overlapped. A piece of tape was cut and applied across the intersection of the two flaps. The base was folded upward, bent across the end flaps, bend downward, and a tab inserted into the base. The assembly was set aside and a mark placed on a tally sheet. After every fifth assembly a new sheet was pulled across in front of the worker and the assembly continued.

MODAPTS DESCRIPTION:

M4G1	grasp sheet
M1P0 X4	break free
M4P0	move into work area
M2G1	grasp front
M2P0	bend upward
M2G1	grasp flap on front
M2P0	bend back
M2G1	grasp flap on back
M2P0	bend forward
M4G1	grasp tape

M2P0	tear off tape strip
M4P2	place tape on flaps
M2G1	grasp base
M3P0	fold upward
M3P0	fold back across flaps
M3P2	fold down and insert tab
M3G1	grasp box for set aside
M4P0	set aside
M4G1	get pencil
M3P2	position pencil
M1P0	make mark
M3P0	set aside pencil

Every fifth cycle:

M4G0	get new sheet
M4P2	pull sheet into place

APPENDIX C. APPLICATION TO IRB

Worker Profile: Learning Patterns for Motor Tasks Among the Physically Disabled

The purpose of this study is to determine how the physically disabled learner modifies manual task performance with experience on the job. Two groups of individuals will be used in this research; one group will be made up of able-bodied students and a second group consisting of individuals with varying levels of physical disability affecting manual dexterity. Each of the two groups will be taught a series of motor tasks of varying difficulty and observed as they repeat each task. Changes in performance will be recorded and compared.

Background

From previous studies of task performance by able-bodied workers it is known that while overall performance improves with worker experience on a job not all motions required by the task improve equally. For able-bodied workers the types of work related motions which are likely to improve with practice are well documented and it is possible to predict how work performance will change as the worker gains experience and which portions of the job should be practiced inorder to obtain the most rapid improvements. Although overall task performance time improves with time on the job not all portions of the task improve uniformly.

Manipulative motions improve more than transportational motions. The portions of motor tasks that are used for transportation involve reaching for an object or moving it from one location to another having already grasped it. Manipulations occur at the end points of transports, such as at the end of a reaching motion when an object is encountered and the initial grasp is made to gain control of the object. Manipulations also occur at the end of transport motions when an object-in-hand is placed at a location or when objects are brought together for assembly, alignment, or tool use. As predicted by Fitts Law, each individual seems to have a natural transport speed that does not change with experience on a task, but manipulation speed increases with practice.

Performance time improvement during the manipulation portions of a task does not appear to result from more rapid hand motion but rather to result from a reduction in the amount of time dedicated to visual feedback. With practice able-bodied workers make less use of visual feedback during the manipulations. They tend to look at an object-to-be-grasped before their moving hand reaches the object and in anticipation of the grasp to shift the gaze point of their eyes off of the object before the fingers actually make contact. As an experienced worker reaches for a part or tool, just before the fingers make contact, visual attention will be redirected to the destination point. Then as the object is moved to its destination the worker's attention shifts off of that point consistently anticipating the next action.

Able-bodied workers have been observed to demonstrate the greatest improvement in the portions of a task on which they initially demonstrated the greatest variability. Transportation motions are performed more consistently in newly learned tasks than are manipulation motions. With experience the range of manipulation performance times does not change greatly but mean performance time is reduced from the slow end of the performance range to near the fastest occurance of the motion as the individual progresses up the learning curve. The inexperienced worker tends to regularly have difficulty making fine manipulations; repeatedly stopping to examine and realign parts and reposition hand grips. The experienced worker finds that the parts fall into place more frequently, although, the occasional fumble still arises.

Three factors have been identified in the learning of manual, industrial tasks - manipulative motions show more improvement than transports, experience on the job reduces the time delays associated with visual feedback, and the parts of the task that show the greatest variability early in the learning process are the portions of the task that have the greatest potential for practice related improvement. Our current study is intended to extend this knowledge to include disabled workers' on-the-job learning and performance.

The Subjects

The majority of subjects used in this study will be selected randomly from the population of physically disabled adults in the New River Valley area. The individuals being sought are people of working age with degraded manual dexterity but who are actively seeking to enter the work force. The two workshops for the disabled in the New River Valley have been helpful in contacting appropriate individuals for Rehabilitation Engineering experiments in the past and have agreed to again publicize our needs for this study. The two workshops will also provide a screening service to eliminate inappropriate subjects from the study (i.e., people without some level of degraded manual dexterity, medically unstable individuals and subjects with other possibly confounding, disabilities).

A small group of able-bodied subjects will be used to develop and validate the test set. The able-bodied subjects will be drawn from the Virginia Tech student population. This control group will be selected to approximate the gender mix and age range of the larger disabled subject group.

All subjects will be paid at the rate of $5.00 per hour of participation.

The Test Set

A set of nine tests of manual dexterity will be used in this study. This set of tests is based on the Workability tests developed by Chris Heyde. Each test in the set involves the use of common household items such as checkers, dominoes, marbles, golf tees, paper cups, playing cards, etc. The objective of each test is to have the subject rearrange objects from a known starting position to a desired goal configuration. The tests vary in the level of dexterity required, the distances over which objects are transported, and the number of repetitions required. The level of difficulty will be modified for each subject to produce a test that is challenging yet achieveable.

Tests will be repeated to demonstrate the effect of experience on learning for each individual participant.

The experiment

The experiment will consist of four phases. The first phase will establish baseline performance for able-bodied individuals and verify the experimental premises for the test set. The second phase will be a preliminary study of the disabled to determine the appropriateness of the tests and methodology for handicapped adults. The third phase is the main study in which disabled subjects will be observed performing all tests. The final phase will be a validation study to determine the relationship of test results to on-the-job performance.

The baseline study will determine if for able-bodied subjects the three experimental premises (more improvement in manipulations than transport motions, improvement where visual feedback induced delays are reduced, and greater improvement of initially variable motions) are in-fact demonstrated with the experimental test set. The baseline study will also provide a basis for performance comparisons in all other phases of the study. The baseline phase of the study will use 5 to 10 able-bodied subjects recruited from the student population at Virginia Tech and will be conducted entirely in the Human Assessment Laboratory (519a Whittemore Hall).

In the preliminary study of the disabled individual tests will be modified to more closely match the residual abilities of the disabled subjects. Dexterity requirements will be determined and an estimate of the number of repetitions of each test needed to demonstrate the learning effect will be developed. The preliminary study will use only disabled subjects and be conducted in a classroom at the New River Valley Workshop, Inc., 103 Duncan Lane, Radford, where all of the participants are currently employed.

The main study will involve 10 to 20 disabled subjects and a smaller number of able-bodied subjects. A full battery of 9 tests will be administered repeatedly to each subject over a period of 3 to 4 hours per day for 3 to 4 days per subject. Subjects will be videotaped and performance times will be recorded. All able-bodied subjects will be tested in the Human Assessment Laboratory. Disabled subjects will be tested either at their place of employment in Radford or in the Human Assessment Laboratory (both cooperating workshops currently offer daily shuttle service between their Radford facilities and the Virginia Tech campus to their employees).

The validation phase of the experiment will use any new employees at the New River Valley Workshop, Inc. who begin work during the period from April 1, 1990 and June 1, 1990. The validation phase of this research will be conducted at the employment site of the disabled participants.

APPENDIX D. GENERAL DESCRIPTION OF EXPERIMENT PROVIDED TO SUBJECTS

The Rehabilitation Laboratory at Virginia Tech is currently investigating learning patterns of disabled workers performing industrial tasks. From previous studies of task performance by able-bodied workers it is known that while overall performance improves with worker experience on a job not all motions required by the task improve equally. For able-bodied workers the types of work related motions which are likely to improve with practice are well documented and it is possible to predict how work performance will change as the worker gains experience and which portions of the job should be practiced inorder to obtain the most rapid improvements. Our current study is intended to extend this knowledge to disabled workers' on-the-job learning and performance.

Participants in this study will be asked to perform a series of challenging manual tasks. The tasks use common household objects such as dominoes, checkers, playing cards, plastic soup dishes, golf tees, nuts, and bolts. For each task you will be shown a starting position for each object and given a goal. For instance, in one task you might be given a bowl of marbles and a second empty bowl and asked to move the marbles one at a time from the first bowl to the second bowl. The object of the tasks is to challenge your manual dexterity and to demonstrate whether practice affects your performance.

Some of the tasks we will time you and on some of the tasks we will videotape your efforts so that we can later review the task for more careful analysis. In either case once the results have been recorded the original time sheets will be destroyed and the tapes will be erased so that your data cannot be identified individually. There is no right or wrong way of doing these tasks. The intent of the study is not to demonstrate how the individual compares to others but rather to help a counselor to help the individual to make the most productive use of existing abilities.

APPENDIX E. INFORMED CONSENT FORMS

The purpose of this document is to obtain your informed consent to participate in an experiment on manual dexterity and motor learning and to inform you of certain rights you have as a participant. The experiment is an investigation of the usefulness of a series of tests of manual dexterity in predicting performance times on certain industrial tasks.

The research is being conducted by the Human Factors Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 24061, telephone number (703) 231-4370. Robert D. Dryden is the principal investigator for the project.

Participation in this study is entirely voluntary. If you choose to participate, your task will be to act the part of a worker in a work simulation environment. The tasks simulated include picking-up small parts, stacking pieces, using simple tools, placing washers and nuts on bolts, inserting plugs in adapters, etc. The experimental sessions will last 3 to 4 hours (including rest breaks). Some participants will be asked to come in on several occasions others will only be needed for 1 session. The maximum number of sessions would be four.

We will be recording your performance on videotape during all active portions of the test. These tapes will be used to verify testing procedures should questions arise after the session. Once all data have been transferred to computer storage identification will be removed and the data treated anonymously.

As a participant in this experiment you have certain rights. The purpose of this form is to describe these rights to you and obtain your written consent to participate.

1) You have the right to discontinue participating in the study at any time. If you decide to terminate the test, inform any member of the research team and they will pay you for the portion of time you have participated.

2) You have the right to inspect your data and withdraw it from the study if you feel you should. In general data are processed and analyzed after a subject has completed the experiment. At that time all identification will be removed and all data will be treated with anonymity. Therefore, if you wish to withdraw your data, you should do so immediately after your participation is completed.

3) You have the right to be informed of the overall results of the experiment. If you wish a synopsis of the results include your address (three monthes hence) with your signature below.

4) You have the right to be informed of the risks involved in participating in this experiment. There are no known risks.

5) You have the right to be informed of any discomfort involved in participating in this experiment. The only known discomfort is possible fatigue resulting from the length of the experimental session. However, you will be permitted to take rest breaks.

Further comments or questions can be addressed to Dr. E. R. Stout, Chairman of the Institutional Review Board for the Use of Human Subjects in Research. He can be contacted at:

Office of Sponsored Programs
301 Burrus Hall
Virginia Polytechnic Institute and
State University
Blacksburg, VA 24061
telephone: (703) 231-5281

Your participation is greatly appreciated. If you have any questions about the experiment or your rights as a participant, please do not hesitate to ask. We will answer your questions as openly and as honestly as possible without biasing the experimental results. We hope that this experiment will be an interesting and enjoyable experience for you.

Your signature below indicates that you have read your rights as a participant, that you understand the time commitment involved, and that you consent to participate. If you include your printed name and address, a summary of the experimental results will be sent to you.

____
(signature)

____
____
____
____

Print name and address if you
wish to receive a summary of
the experimental results.

John Thomas Ward was born on the second of June 1947 in Princeton, New Jersey. After receiving the B.S. degree from Rutgers University in June of 1975 he taught computer languages as a member of the adjutant faculty at Rutgers. While employed by Computer Sciences Corporation Mr. Ward acted as lead programmer and later team leader on data base development projects for the U.S. Army Training and Indoctrination Command (TRADOC), Ft. Monroe, Virginia. As a senior systems analyst for Kentron International, Inc. he designed vehicle simulations for NASA/Langley Research Center, Hampton, Virginia. After serving a one year Human Factors Internship at Honeywell Inc. Mr. Ward received the M.S. (1988) and Ph.D. (1990) degrees from Virginia Tech in Industrial Engineering and Operations Research - Human Factors Option.

Mr. Ward is a member of the Human Factors Society, the Association of Computing Machines (ACM), the Americal Association for the Advancement of Science (AAAS), the Society for Information Display (SID), and Alpha Pi Mu, an honor society for industrial engineers. He is currently Director of Research at the Institute for Technology Development, Advanced Living Systems Division in Oxford, Mississippi. Mr. Ward's interests include human factors engineering, the assessment of staffed system performance, the modeling of human behavior, and the application of technology for the improvement of the quality of life in residential, work, and recreational environments.