Construction and use of Biomechanical Profiles to determine degree of difficulty in a task, the level of training, skill, and aptitude of a worker, and to demonstrate better methods that improve performance. Example illustrates application.

E. R. TICHAUER, H. GAGE, L. B. HARRISON, New York University, New York, New York

Use of Biomechanical Profiles in work

It is the purpose of this paper to show how Biomechanical Profiles are constructed and how they can be applied to estimate the ease or difficulty with which a task can be performed. Likewise, the status of training, skill, and aptitude of the individual assigned to a job can be evaluated. Finally it is shown how a Biomechanical Profile can be employed to counsel workers with respect to attaining more proficient levels of performance. The example chosen is a simulated assembly task requiring a fairly high level of eye-hand coordination.

Background

Since the beginnings of scientific management, Reference 1, most practitioners of work measurement have evaluated the efficiency of manual work principally on a time basis. A notable exception were the Gilbreths, who first questioned industrial standards for performance with respect to their relationship to the physical and emotional effort expended by a worker as related to the specific geometry of workplace design, as well as to the general physical factory environment, Reference 2.

These early workers already fully established the scientific rationale behind the disciplines of ergonomics and biomechanics as practiced today. Nevertheless they lacked instrumentation adequate to conduct experimental investigations into the physical effort expended by individual muscles in the performances of specific tasks. Likewise, the sequencing of action and effort levels of the various muscles involved in manipulative and other body maneuvers were beyond the investigative technology available then.

The Gilbreths were simply fifty years ahead of their time. Their motion measurement devices, such as the ergograph and chronocyclograph, were restricted to the taxonomic description of displacement patterns of external anatomical reference points during motion. No physiological or functional input-output relationships between muscular activity and motion produced could be established by the pioneers of work measurement.

The first mention, in 1925, of electrophysiological processes as basic to the scientific study of work is found in the works of Segur: "The basis of Motion-Time-Analysis lies (in the fact) that the mechanism of the human body is primarily a chemical engine. . . . Average speed of a nerve reaction . . . is 0.000045 minute per foot. . . . average number of messages (per) nerve path . . . is 5,000 per minute. . . . average time to complete a . . . response to a nerve impulse is 0.000064 minute . . . The units into which these reaction times are built depend entirely upon the intended use of the data. For a fixed use, they can be built into a simple set of standards," Reference 3.

At the same time, and unknown to Segur, a report was published by Adrian, Reference 4, in which he stated that the level of electrical activity in human muscle could be measured during movement. This author was among the first to use the term electromyography. From Adrian onwards, the development of electromyography for medical purposes has been practically a continuous process.

Karpovich, Reference 5, was among the first to use electrogoniometry in the measurement of range and strength of joint motion of athletes. Somewhat later, Basmajian, Reference 6, used electromyograms as descriptive indices of muscle sequencing in occupational maneuvers. About this time, electrophysiological instrumentation and procedures were sufficiently advanced to encourage the development of applications of electromyographic kinesiology to work study. Notable contributors were Carlsöö, Jonsson and Steen, and Pauly and Scheving, References 7, 8 and 9.

As a result of recent developments in electronics, both electrogoniometry and electromyography have been refined to yield a variety of parameters of human movement. In 1968, Tichauer, Reference 10, selected the most important of these parameters and combined them into a simultaneous and single recording which he named the "Biomechanical Profile" — a term which is now generally accepted.

measurement

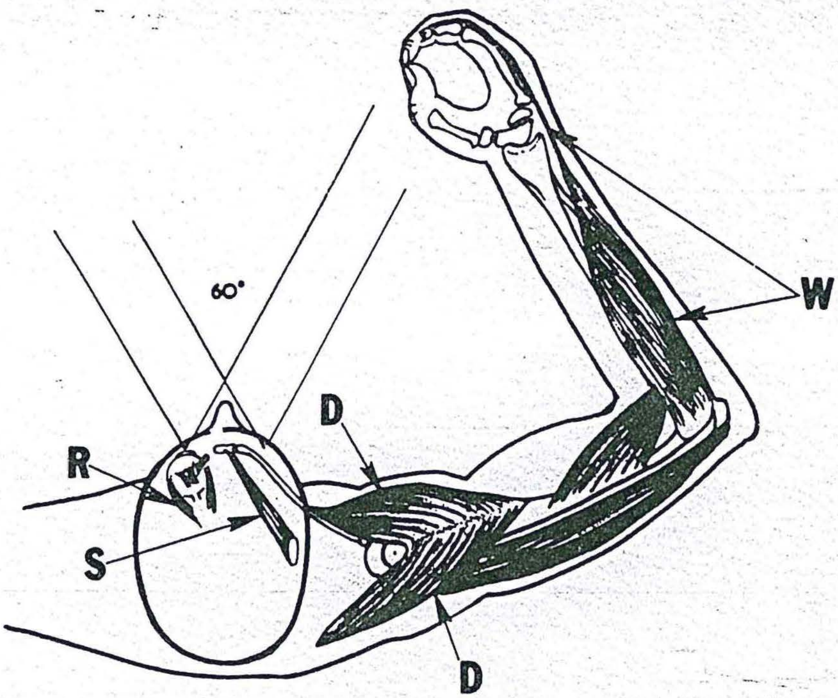


Figure 1. The kinetic chain constructed for industrial practice links the major sensory organs and key muscles required to perform a task. In eye-hand coordination, sensory input to the eyes is inferred by monitoring the small muscles (R) which rotate the eyeball. To see objects outside a binocular visual cone of 60 degrees, the head must be moved, using (S) the sterno-mastoid muscles of the neck. Arm movement at the shoulder is produced by (D) the deltoid muscle. Wrist movement is produced by (W) the extensor muscles of the forearm.

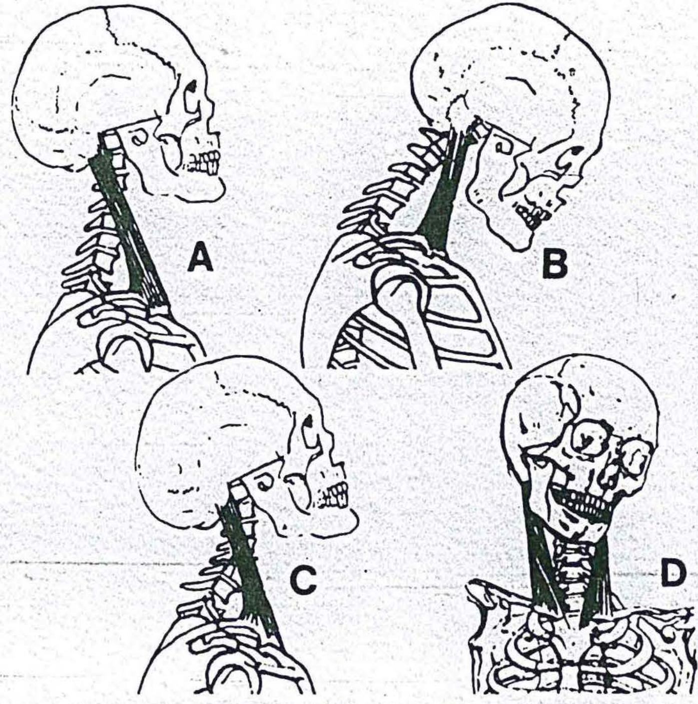
Rationale

The first step in the development of a Biomechanical Profile is the construction of a "kinetic chain," which links the sensory input or feedback from the workplace with the muscular output required to perform a task. To enumerate all anatomical structures of a kinetic chain is cumbersome and often unnecessary. In industrial practice, the kinetic chain comprises only major sensory organs and key muscles.

Motion sequences obtained by indirect measurement. The kinetic chain of eye-hand coordination begins with a sensory input from the workplace to the eyes. Frequently, the nature and size of activity of some of the elements in a kinetic chain can only be obtained indirectly. For example, eye movement can not easily be measured directly, but may be inferred by monitoring the signal intensity of the small muscles which rotate the eyeball, Figure 1 (R). The signal is picked up at the temples.

All objects must be located within a visual cone of 60 degrees to be seen by both eyes simultaneously. Because of the lack of binocular vision outside of this cone, judgments of object size and of distance from the viewer can not be made. Whenever eye scanning alone becomes inadequate, head movement must be added. Under circumstances it is also impractical to measure head movement directly. However

Figure 2. Head movement is often impractical to measure directly. However, monitoring the activity of the sterno-mastoid muscles is an adequate, although indirect, measure of head movement since these muscles are in constant use whether the head is (A) held straight; (B) lowered; (C) raised; or (D) tilted to either side.



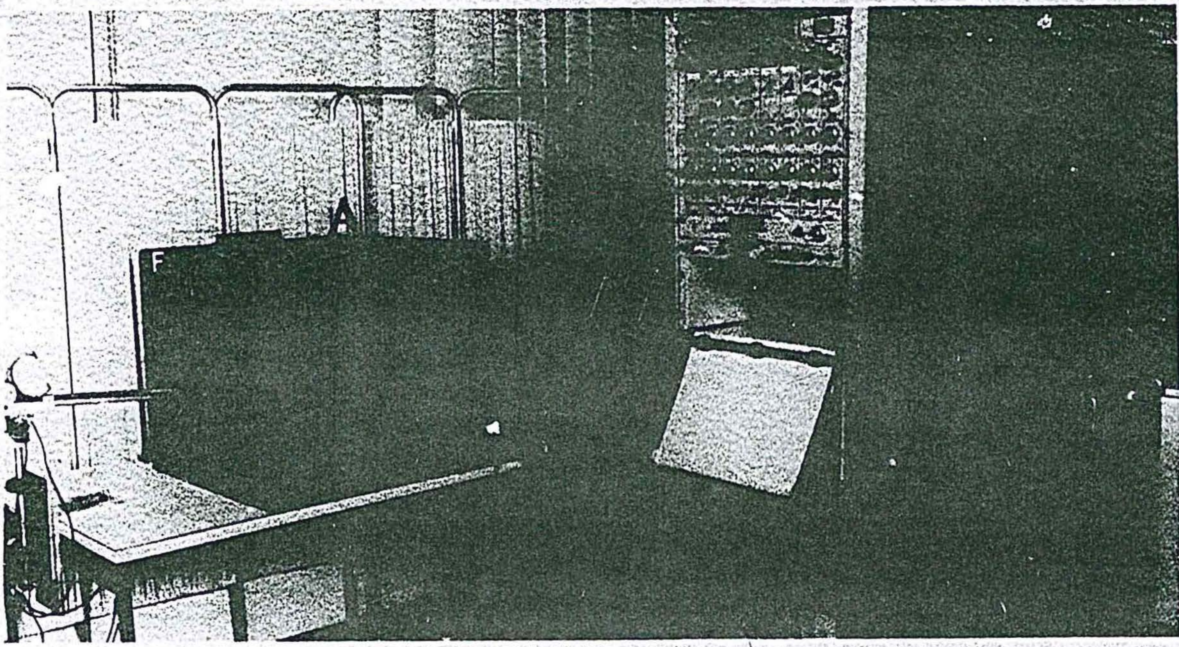


Figure 3. The apparatus used in this experiment consists of a task board (A) and a metal-tipped tool (B). When any of the 19 lights on the task board is touched by the tool it is extinguished and another bulb switches on. The tool movement generates voltage signals in three potentiometers (C). The output of this kinesiometer is converted by an analog computation module (D). Also at (D) are the interchangeable patch boards which program the light patterns to simulate any occupational motion pattern. The chart recorder E) displays the complete Biomechanical Profile. Signals are stored in analog form on a multi-channel tape recorder (F) for computer processing.

it is often sufficient to monitor the activity of the sterno-mastoid muscles in the neck, Figure 2. These muscles are involved in head movement in any direction. The magnitude of the signal is roughly but adequately proportional to the total level of head motion.

In this kinetic chain, myograms of eye and head muscles are used as indirect measures of displacement and not as indicators of muscular effort.

Electrophysiological parameters. Muscular effort *per se* is obtained from the principle muscles involved in the movement. These muscles are: the deltoid, Figure 1 (D) which controls arm movement at the shoulder, and the wrist extensors, Figure 1 (W) which control wrist movement, and which by their activity reflect fine manipulation. The activity of the flexors and extensors of the forearm were purposely excluded from myographic recording following the normal good practice of limiting data gathering to the most important and most directly involved elements of the kinetic chain.

Thus, for the assembly task chosen in this example, the kinetic chain involves:

1. Eye movement — produced by the small muscles which move the eyeball, Figure 1 (R).
2. Head movement — produced by the muscles of the neck, Figure 1 (S).
3. Arm movement at the shoulder — produced by the deltoid muscle, Figure 1 (D).
4. Wrist movement — produced by the extensor muscles of the forearm, Figure 1 (W).

These muscles complete the kinetic chain, but it should be stressed that the Biomechanical Profile is used to measure the effectiveness of this chain within a man-task system.

After the kinetic chain has been identified, those events which describe the work and effort required by the task under study are measured.

Biomechanical parameters. Biomechanical parameters are output measurements which are not necessarily related to physiological factors, but rather to performance elements in a man-task system. For eye-hand coordination, the three parameters of actual tool movement — displacement, velocity and acceleration — are included as measures of output efficiency. The displacement signal indicates the range and pattern of motion. Velocity serves as an index of both speed and strength. Acceleration reflects control over the precision and quality of motion. Lack of such control leads to imprecise movements at the workplace due to the inability to terminate a movement at the correct place and time.

The biomechanical parameters can me measured with a kinesiometer, Figure 3 (C). Both muscular effort and the sequencing of muscles in the production and termination of movement can be obtained through electromyographic recording of the contractile activity of the muscles concerned.

Electromyographic technique. The success of myography in an industrial environment depends on choosing the proper technique. In most instances, "direct" myogram does not yield useful results. Figure 4 shows a direct myogram simultaneously recorded by an oscilloscope and a paper recorder at exactly the same sensitivities and speeds. There are only five points of similarity between the tracings because the speed of the signal exceeds the rise time and slew rate of commercial chart recorders.

Figure 5 shows how a modification of the so-called "integrated" myogram yields repeatable and reliable recordings. The signal produced here represents the analog of the firing rate which is indicative of total activity in a given muscle mass at any instant during the sampling period. This technique produces a signal compatible with the frequency response of a normal paper recorder. The resulting tracing represents a history of muscular activity in terms of sequencing, coordination and effort levels.

Apparatus

The apparatus, Figure 3, used in this experiment consists of a task board (A) with lights installed on it and wired so that only one light is on at any time. A metal tipped "tool" (B) is mounted on a lightweight rod which slides in a "gimbal" type mount. As soon as a light is touched by the tool, it goes off and another bulb automatically switches on. The movement of the tool in space generates voltage signals in a set of three potentiometers (C) that are converted by an analog computation module (D) into outputs which are proportional to the vector sums of each displacement, velocity and acceleration of the tool tip measured against time.

The board contains 19 lights and contact points, arranged in three-dimensional space to correspond with those reach situations most commonly encountered in industrial work. The light pattern can be programmed through interchangeable patch boards to simulate occupational motion patterns for a wide range of industries, such as food processing, electronic assembly, or the needle trades.

Thus, the output from the analog computation module produces the three directly measured biomechanical parameters of the task. These are recorded simultaneously with the indirectly measured biomechanical parameters of the kinetic chain — here: head and eye movement, and the electromyographic signals

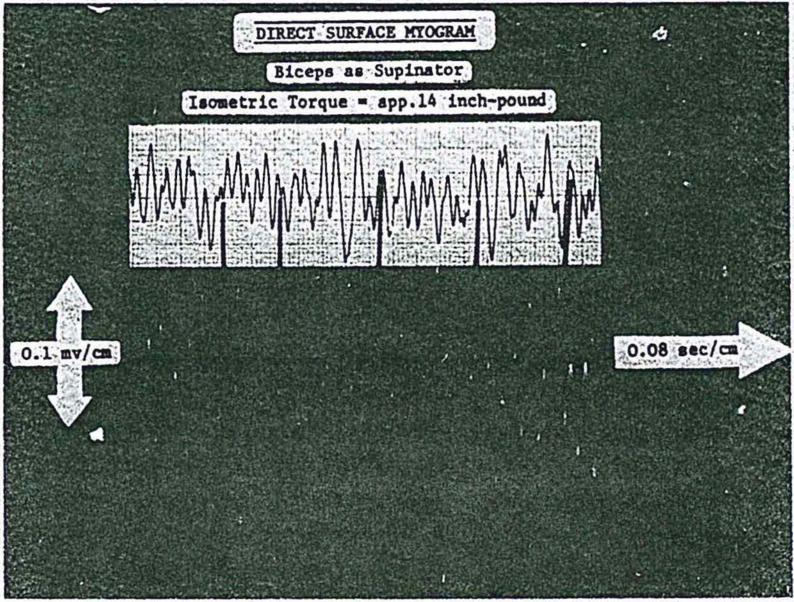
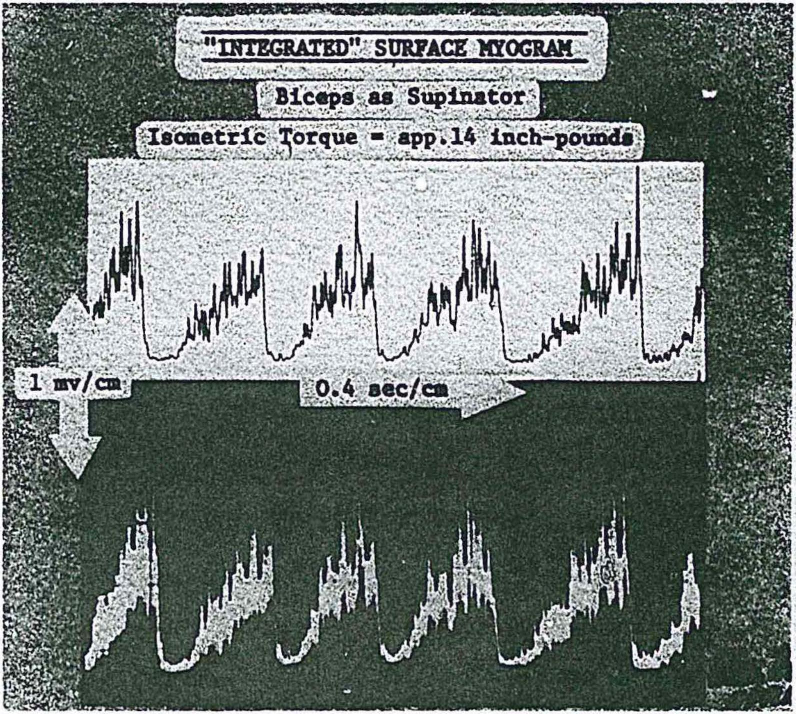


Figure 4. A simultaneous recording of the biceps muscle firing pattern displayed on a chart recorder (upper half) and an oscilloscope (lower half) at exactly the same sensitivity and speed. Only five points of similarity are evident, because the signal speed of the myogram exceeds the rise time and slew rate of commercial chart recorders.

Figure 5. The same biceps contraction pattern as shown in Figure 4: chart recorder in upper half, oscilloscope in lower half. However the signals here have been conditioned by summing all action potentials overtime so that the trace now represents the analog of the firing rate, which is indicative of the total activity of the muscle mass at any instant during the sampling period. The signals are fully compatible with the frequency response of the chart recorder. The integrated myogram produces repeatable and very reliable measurements of muscular activity levels.



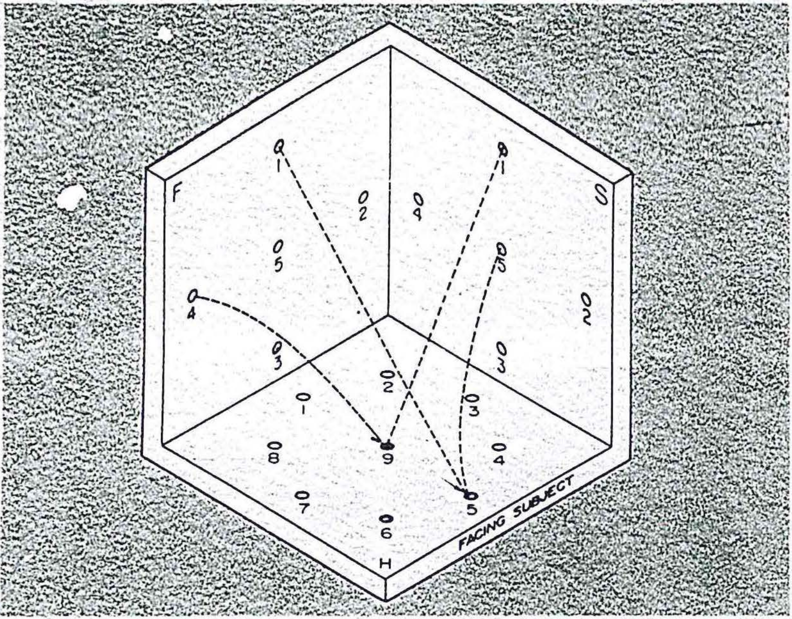
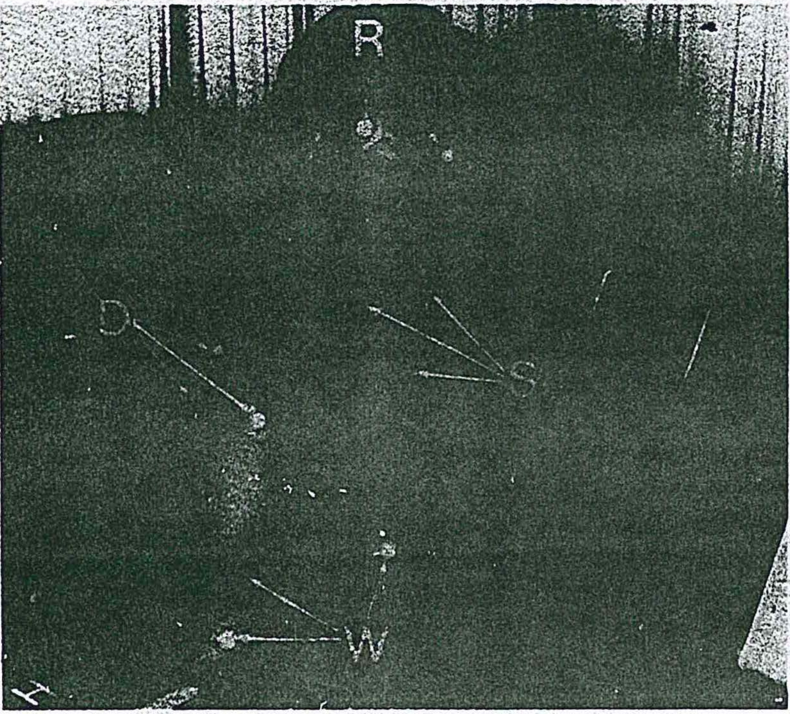


Figure 6. The motion pathways on the task board are sequenced by the individual target lights. The front (F) and side (S) panels are laid out in accordance with the commonly accepted "normal reach" areas. All reaches begin and end in the normal horizontal (H) industrial assembly area — H-5 and H-9. Each location is coded through the logic of its circuitry so that it is easily identifiable during subsequent analysis of the Biomechanical Profile.

Figure 7. Four sets of surface electrodes were placed on each subject, over the muscles comprising the kinetic chain, as pictured in Figure 1. In each set, the third electrode acts as the ground. Electrodes were positioned according to standard muscle testing procedures, so that each myogram obtained represented a maximum amount of contracting muscle mass. All subjects were representative of the female working population commonly found performing manual production work in industry.



from the shoulder and wrist. These seven parameters, displayed on the chart recorder (E), constitute the complete Biomechanical Profile for this task. When computer processing is desirable, the signals are stored in analog form on the multichannel tape recorder(F).

Procedure

Twelve women ranging in age from 35 to 50, and earning their living through manual production work, were hired for the experiment. In each case visual acuity was either normal or fully corrected; state of health was normal for the particular age. All were right-handed. Thus the subjects were homogeneous and representative of the female working population commonly found performing similar tasks in industry. A number of practice trials sufficient to bring each individual up to acceptable performance levels were allowed.

Two sequences of 75 lights each were programmed. Subjects were exposed to two replications of each program in alternate fashion. In all trials, motion pathways began and ended in the normal industrial assembly area, Figure 6, H-5 and H-9. Because the task board is laid out in accordance with commonly accepted "normal reach areas" — Squires, Reference 11 — these motions simulate typical "reach" and "move" work situations. Each location is coded through the logic of the circuity so that its starting and end points are easily identified during subsequent analysis. Work surface height, the configuration of the chair, distance from the table and other features of the workplace were adjusted for optimal posture and standardized geometry of motion pattern. Likewise the power grip was used throughout the experiment to assure uniformity of manipulative process. Thus all individuals employed the same work method.

All subjects were electroded according to the arrangement shown in Figure 7. Electrodes were positioned so that each myogram obtained represented a maximum amount of contracting muscle mass. These optimal positions were established from standard muscle testing procedures developed by Kendall and Kendall, Reference 12. All subjects completed four replications of the task sequence, and results were sufficiently uniform so that further testing was not necessary.

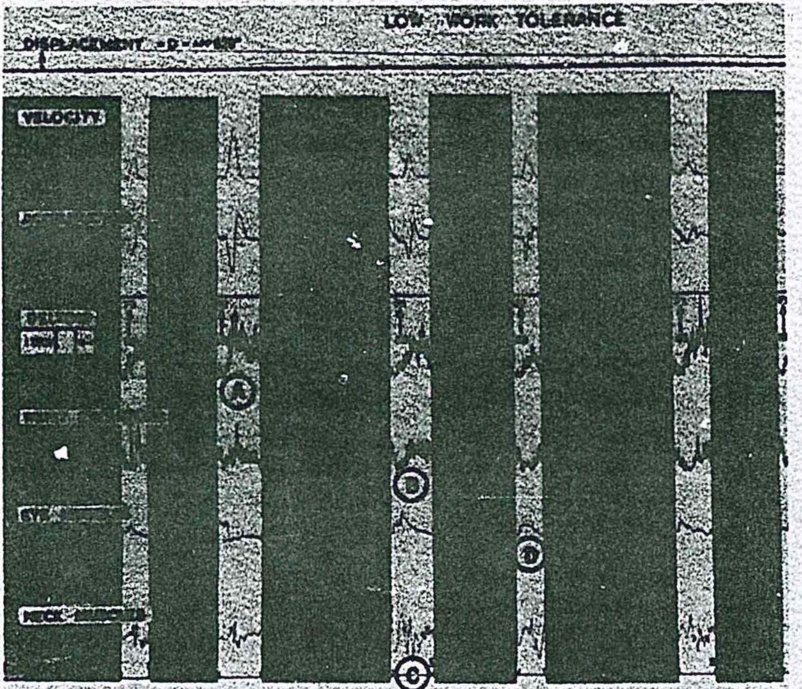
Results

The Biomechanical Profiles generated make it possible to distinguish between individuals who are likely to have low or high work tolerance. Two workers performed exactly the same task sequence — a number of forward reaches, Figures 8 and 9. Although their production times are approximately equal, the effort required to produce these outputs is markedly different. The firing rate in the deltoid muscle, particularly at low velocity, is commonly far higher for individuals of low work tolerance, Figure 8 (A), while the wrist extensor signal is continuous and unstructured, (B). Both of the factors are likely to be indicative of relatively high effort accompanied by poor efficiency of performance. Also, it can be seen from the traces of neck muscle activity, (C), that too much of the scanning is being done by the head. The lack of purposeful anticipatory eye scanning following a single head movement, (D), is also a good predictor of inferior performance.

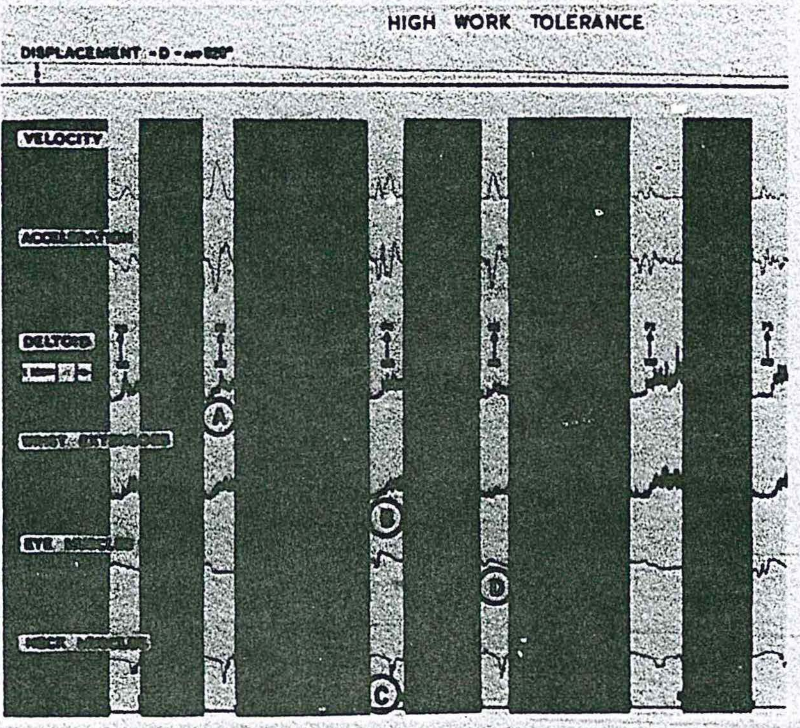
Analysis of these contrasting Biomechanical Profiles can be used to assert that, unless retrained, the low tolerance worker will: be unable to produce work of sufficient quality for sustained periods, eventually deviate widely from time standards, and be subject to premature fatigue and the subsequent risk of accidents or quality breakdowns.

Figure 10 shows that directionality of motion can affect performance time. This invalidates assumptions common to most systems of predetermined motion times, which state that a movement from A to B is equivalent to one from B to A. A reach away from the body takes longer to accomplish than a motion made towards the body. Reaching away is a more difficult movement because the resistance to stretching of the large muscles of the back must be overcome. Therefore, progressive rather than reciprocating motion pathways should be used.

The Biomechanical Profile can establish the status and quality of an individual's training, as well as identify work mannerisms which



Figures 8 and 9. Biomechanical Profiles can be used to distinguish between individuals who are likely to have low or high work tolerance. Two workers performed a number of forward reaches. The firing rate in the deltoid (A) muscle, particularly at low velocity, is commonly far higher for individuals of low work tolerance, left, while the wrist extensors' myograms (B) of such workers are continuous and unstructured. Both of these factors are likely to be indicative of relatively high effort accompanied by poor efficiency of performance; e.g., the worker manipulates for fine positioning before arriving at the target. Neck muscles' activity (C) show that the low tolerance worker does too much of the scanning with the head. The lack or presence of purposeful anticipatory eye scanning (D) is also a good predictor of sustained performance ability.



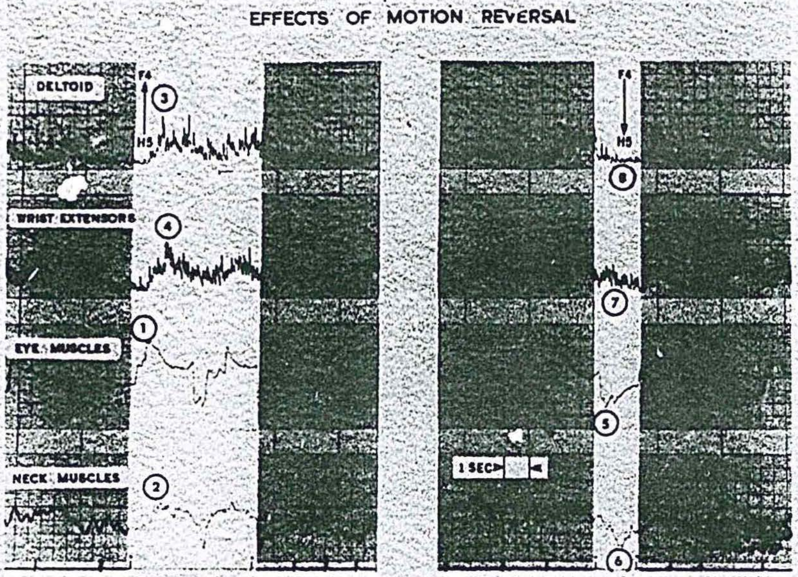
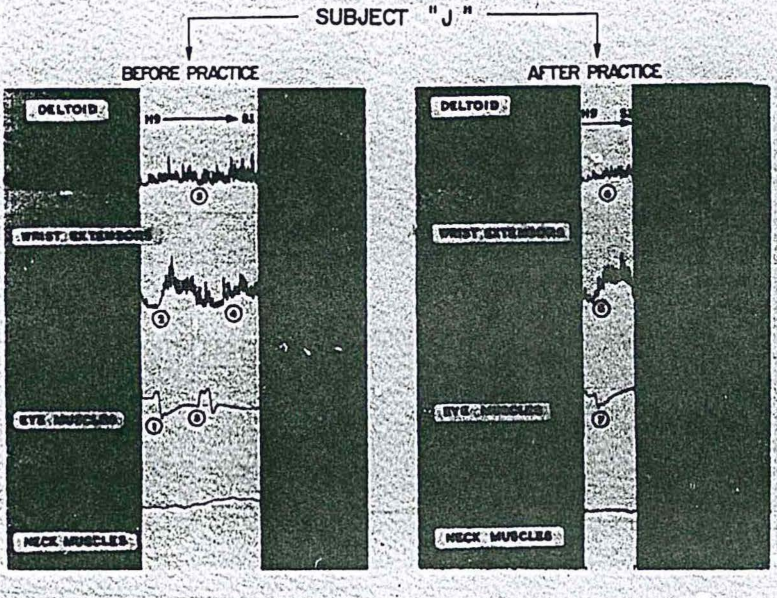


Figure 10. Directionality of motion can affect performance time. Throughout this experiment a reach away from the body took longer than a motion towards the body, invalidating assumptions common to most systems of predetermined motion times. In a movement up and away from the body, resistance of the large muscles of the shoulder and back must be overcome; down and towards the body, the arm behaves as a ballistic pendulum, requiring minimal effort and control for effective performances.

Figure 11. The state and quality of a worker's training can be measured by electromyographic kinesiology, and the work habits which need retaining can be pinpointed. Before practice (left), the subject moves her eyes to search (1), then moves her wrist (2), looks again (3), finally does useful work with her wrist as she positions a second time (4). During the entire motion (which goes from the horizontal to a side target point), the deltoid (5) is under constant tension since the elbows are kept high as the shoulder is moved. The total motion consumes 4.7 seconds. The practiced performance (right) resulted from proper training. The subject carried out instructions such as: "deep the elbows down." Deltoid activity is minimal (6); eye movement (7) is purposeful and efficient. Subject "J" looks first, scanning the entire visual field; the wrist (8) is then moved to the located target. The trained subject needs less than half the reach time.



should be eliminated through reinstruction. Figure 11 shows "before practice" and "after practice" performances of the same individual reaching sidewards away from the body and back. The untrained worker lacks coordination between scanning and wrist movement: her deltoid is in constant tension, indicating that she is in violation of one of the basic prerequisites of work tolerance: "Keep the elbows down," Reference 13.

Such workers should be counseled to look straight at the target, then proceed to reach for it without dependence on further visual correction, reserving the strongest activity of the wrist for the end of the sequence, when fine positioning takes place. In the "after practice" Profile recorded, eye and wrist movements are now in proper sequence. Deltoid activity has declined. Thus, the level of effort has decreased while performance speed has doubled.

Conclusions

The Biomechanical Profile recorded by the apparatus used in this experiment can be used for objective work and effort measurement as well as rating. Hence it is an effective aid to industrial engineers.

Realistic and reliable time standards can be set for industrial tasks, based upon proper analyses of the Profile. Such analyses permit long-term projections of performance level and work tolerance. Reliable projections of fatigue and its influence on workers can also be made. It should be noted that, in many cases, qualitative analysis of the recorded Profile is sufficient to provide objective evaluation.

Among the other applications of the apparatus developed in this experiment for recording the Biomechanical Profile is the developing of optimum workplace layouts and motion patterns for a new product or process, even prior to trial runs. This application also allows the training of workers for a new or proprietary manufacturing process without disclosing the nature of the product or process too early. By programming the task board for the desired motion pattern, specific errors of deficient operators can be pinpointed; the individual can be retrained or screened out in the hiring for a specific task.

References

(1) Taylor, F. W., *Scientific Management*, Harper and Brothers, New York, 1947.

(2) Gilbreth, F. B., *Motion Study,* Van Nostrand Company, New York, 1911.

(3) Segur, A. B., "Motion Time Analysis," in *Industrial Engineers Handbook,* 1st Edition, H. B. Maynard (editor), McGraw-Hill Book Company, New York, 1956.

(4) Adrian, E. D., "Interpretation of the Electromyogram," *Lancet,* Nos. 5311 and 5312, 1925.

(5) Karpovich, P. V., and G. P. Karpovich, "Electrogoniometer: A New Device for the Study of Joints in Action," *Federation Proceedings,* Volume 18, 1959.

(6) Basmajian, J. V., *Muscles Alive,* Williams and Wilkens Company, Baltimore, Maryland, 1967.

(7) Carlsöö, S., "The Static Muscle Load in Different Work Positions; and Electromyographic Study," *Ergonomics,* Volume 4, No. 3, 1961.

(8) Jonsson, B., and B. Steen, "Function of the Hip Joint and Thigh Muscles in Romberg's Test and Standing at Ease' - an Electromyographic Study," *Acta Morphologica Neerlando-Scandinavica,* Volume 5, 1963.

(9) Pauly, J. E., and L. E. Scheving, "An Electromyographic Study for Some Hip and Thigh Muscles in Man," *Proceedings of the 1st International Conference of Electromyographic Kinesiology, Electromyography,* Supplement 1, (Addendum Volume 8), Montreal, Canada, August 1968.

(10) Tichauer, E. R., "Electromyographic Kinesiology in the Analysis of Work Situations and Hand Tools," *Proceedings of the 1st International Conference of Electromyographic Kinesiology, Electromyography,* Supplement 1, (Addendum Volume 8), Montreal, Canada, August 1968.

(11) Squires, P. C., "The Shape of the Normal Work Area," Report No. 275, U. S. Navy, Bureau of Medicine and Surgery, Medical Research Laboratory, New London, Connecticut, 1956.

(12) Kendall, H. O., and F. P. Kendall, *Muscles, Testing and Function,* Williams and Wilkens Company, Baltimore, Maryland, 1949.

(13) Tichauer, E. R., "Biomechanical Standards for Workplace Design," New York University Note, New York, 1970.

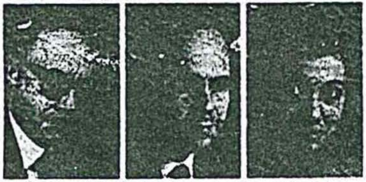
(14) Ayoub, M. M., "Effect of Weight and Distance Traveled on Body Member Acceleration and Velocity for Three Dimensional Moves," Doctoral Dissertation, State University of Iowa, Iowa City, Iowa, August 1964.

(15) Tichauer, E. R., S. W. Davis and G. Schulz, "The Biomechanical Profile of Pronation and Supination and its Clinical Applications," *Archives of Physical Medicine and Rehabilitation,* Volume 51, No. 12, December 1970.

Acknowledgements

The kinesiometer, Figure 3(C) is an improvement of an apparatus first used by Ayoub, Reference 14. The total concept of apparatus and task was developed by E. R. Tichauer, Sc.D., Reference 15. The equipment was designed by R. Tietjen, M.D., and R. Schoonmaker, M.D. C. Gold, M.S., and G. Tamulonis, M.S., developed the circuity. H. Gage, M.M.E., and L. Harrison, B.A., designed and conducted the experiment. Thanks are due to P. Hagood and V. Murray who coordinated subject participation and H. Tichauer who rendered the illustrations. The assistance of J. Goodgold, M.D., who made this study physically possible, is gratefully acknowledged.

This study was supported by a grant from the National Institute of Occupational Safety and Health, and to some degree by the Social and Rehabilitation Service of the U.S. Department of Health, Education and Welfare under the designation of New York University as a Research and Training Center.



Erwin R. Tichauer is Professor and Director of the Division of Biomechanics at The Center for Safety and at the Institute of Rehabilitation Medicine of New York University. He also directs the nation's only specialized graduate training program in Occupational Biomechanics.

Educated at the Technische Hochscule (Germany), Dr. Tichauer holds an ScD from Albertus University.

A senior member of AIIE, Dr. Tichauer is also an honorary member of Alpha Pi Mu, Fellow of the Royal Society of Health (England), and Chairman of the Biomedical Engineering Section of The New York Academy of Medicine. He is a recipient of SMA's Gilbreth Medal, the Outstanding Achievement Award of AIIE's Work Measurement and Methods Engineering Division, and AIIE's Dr. David F. Baker Distinguished Research Award. Dr. Tichauer is both a professional engineer and a professional anatomist.

Howard Gage is a Research Fellow at the Division of Biomechanics, New York University, under the auspices of the National Institute for Occupational Safety and Health. Formerly, he was a research engineer at Grumman Aerospace Corporation and a consultant in biomechanics to Procter and Gamble and RCA.

Mr. Gage holds a bachelor's degree from City College of New York and a master's degree from New York University College of Engineering and Science. He is a former Chairman of the Biomechanics Division of ASME.

Lynne B. Harrison holds a Research Fellowship awarded by the National Institute for Occupational Safety and Health in the Division of Biomechanics, New York University. She has been an associate editor of Modern Plastics Encyclopedia and a research associate of The Physicians for Automotive Safety. Mrs. Harrison holds a BA from Hunter College.

IE INDUSTRIAL ENGINEERING CONTENTS

Volume 4, No. 5 / May 1972

Data collection is almost error-free WILSON F. GRABILL, JR. 12

Data collection system — controlled by mini-computer — moves shop data more accurately, faster, and at a net savings besides.

Portable booth for hearing tests 17

Testing method meets requirements of Federal Occupational Safety and Health Act for testing employees subjected to excessive noise levels.

Nomograph simplifies excess inventory problem J. W. FOSTER, R. C. HIGGINS 18

Many inventories are peppered with excess stock. Here's method of determining economics of reducing excess, with nomograph to simplify use.

Use of Biomechanical Profiles in work measurement E. R. TICHAUER, H. GAGE, L. B. HARRISON 20

Their construction and application to determine task difficulty and worker's aptitude, to demonstrate better methods. Example illustrates use.

Learning curves that work S. N. GOEL, R. H. BECKNELL 28

Computer program determines learning curve for an operation with inputs of starting efficiency, learning rate, and operation time standards.

Productivity in the 70's 32

John E. Morrissey, National Commission on Productivity, will address a general session of the 23rd Annual Conference and Convention.

1972 honors and awards 33

AIIE annual honors and awards will be presented in Anaheim during 23rd Annual Conference and Convention. Here are this year's recipients.

AIIE — what now? ROBERT W. LOCKWOOD 37

In planning for the future, the Board of Directors is preparing a report of long-range objectives. Your ideas are invited.

Collective Action Task Force wants inputs of AIIE members 38

In conformity with a resolution of the 22nd Annual Convention of AIIE, the Board of Trustees appointed a task force. Here is its first report to members.

MTM

ASSOCIATION

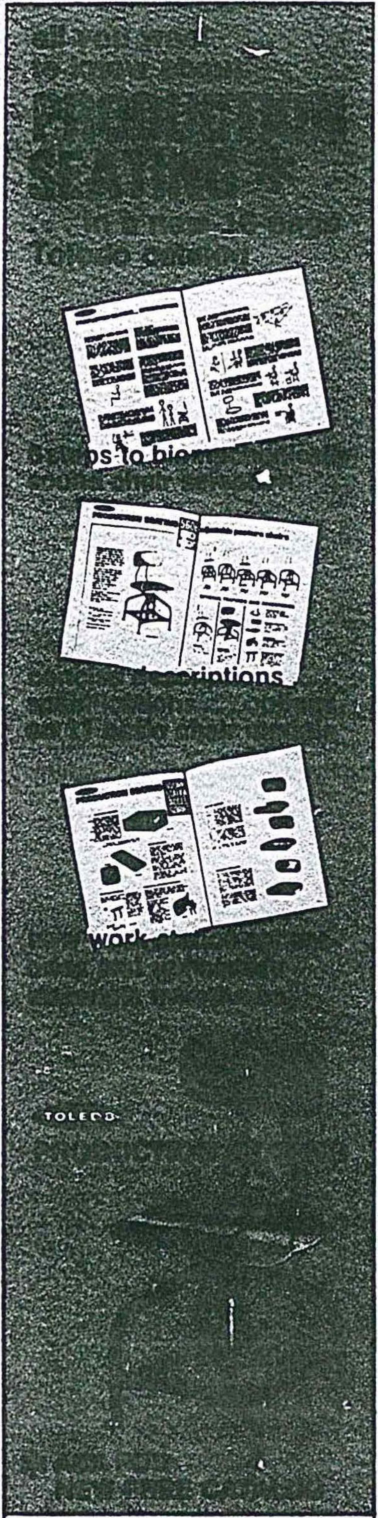
ANNOUNCING . . .
TRAINING IN
MTM SYSTEMS

- ☐ MTM-1 . . . . The basic MTM system used throughout the world . . . a 3-week course. No MTM training required as prerequisite. Leads to MTM Association Blue-Card certification in MTM-1.
- ☐ MTM-2 . . . . The second-level of synthesized MTM data . . . a 1-week course. MTM-1 certification is prerequisite. Leads to MTM Association Blue-Card certification in MTM-2.
- ☐ MTM-2 . . . . Training in MTM-2, work simplification and MTM-1 appreciation . . . a 2-week course. No prerequisite MTM training required. Leads to MTM Association Blue-Card certification in MTM-2.
- ☐ MTM-3 . . . . The third-level system based on basic MTM used for small batch and long-cycle operations . . . a 3-day course. Certification in MTM-2 is prerequisite. Leads to MTM Association Blue-Card certification in MTM-3.

All courses are highly useful to industrial engineers, process engineers, managers and others working in areas of time prediction and work analysis.

Write now for full details from:
James P. O'Brien
Executive Director
MTM Association for
Standards and Research
9-10 Saddle River Road
Fair Lawn, New Jersey 07410

Circle 2 on Reader Service Card



Toledo Metal Furniture Co.
2700 S. Hastings
Toledo, Ohio 43607

Gentlemen: Please send free catalog and Seating Analysis Forms.

Name ____________
Position ____________
Company ____________
Address ____________
City ____________ Zip ____________

Circle 3 on Reader Service Card

JIM F. WOLBRINK
Publisher

Editorial Staff

ROBERT S. RICE
Editor
ABBIE COHEN
Assistant Editor
NANCY Z. REYNOLDS
Editorial Assistant
JAN V. WHITE
Art Editor

Editorial Committee

WARREN E. ALBERTS
United Air Lines
ROBERT L. HENNESSY
Southern California Gas Company
H. B. MAYNARD
Maynard Research Council, Incorporated
JAMES F. MCGOVERN
Management Concepts & Practices Company
WILLIAM A. SMITH, JR.
Lehigh University
A. JOHN GEIS
National Graphics

Vice President — Publications

GUY J. BACCI, II
International Harvester Company

Publications Policy Board

WILLIAM R. SWETT
IBM Corporation
PAUL E. TORGERSEN
Virginia Polytechnic Institute and State University
ROBERT H. JEFFERS
Sears Roebuck and Company

Advertising Sales

DONALD C. PORTEOUS, JR.
Sales Manager
JOAN DE SALVO, *Sales Service*
Industrial Engineering
345 East 47th Street, New York
N. Y. 10017, 212-752-6800, ext. 238

ALBERT D. SHONK COMPANY
681 Market Street, San Francisco,
California 94105 415 392-7144

3156 Wilshire Blvd., Los Angeles,
California 90010 213-388-2981

Published monthly by the American Institute of Industrial Engineers, Inc., Executive and Editorial Offices — 345 East 47 Street, New York, New York 10017.

Copyright 1972 by the American Institute of Industrial Engineers, Inc. Write Editorial Offices for reprint permission.

AIIE accepts no responsibility in connection with any liability which might develop as a result of material published; opinions expressed are those of the authors and do not necessarily represent the Institute. *Industrial Engineering* is not a refereed publication.

Subscription rates. Domestic: one year — $20.00; two years — $33.00; three years — $45.00. Foreign: one year — $22.00; two years — $35.00; three years — $48.00. Single copies — $2.50.

All issues of Industrial Engineering are available on microfilm or Xerox copy from University Microfilms, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

Second class postage paid at New York, N. Y. and at additional mailing offices.