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# PROTECTION AND FUNCTIONING OF THE HANDS IN COLD CLIMATES

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*John Lyman: The Effects of Equipment Design  
on Manual Performance*

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## **THE EFFECTS OF EQUIPMENT DESIGN ON MANUAL PERFORMANCE**

**JOHN LYMAN**

The title assigned to this report is an ambitious one indeed. In my opinion, relative to the amount yet to be learned, we do not know very much about the effects of equipment design on manual performance. At least, we do not know enough to put much confidence in design decisions made at the pencil-and-paper level which, from an economic standpoint, is the best place to make design decisions — if you can have confidence. Despite the rather vigorous research efforts which are underway in the area of manual skill in various laboratories in this country and in Europe, we probably will not have defined all of the important equipment design parameters which relate to manual performance during the next several years. The problems associated

with the quantitative detailing of information about man-equipment interactions into a form which can be readily utilized by equipment designers is a task which will occupy much additional time once the relative importance of the various design parameters has been discovered. This means that a sophisticated technology, with a high degree of quantitative analysis and synthesis beyond the "informed guess" stage appears to be a long range matter. It is a matter full of challenging and frustrating problems, where high grade research is especially difficult. This is both because of the general complexity of the interactions among the variables of men and equipment and because of a history in which experimental discoveries in the field have tended to be specific to particular situations, making it necessary to work rather closely to a context of desired application in order to solve *ad hoc* problems. Unfortunately for rapid progress, these problems apparently have often been dictated by the urgency of expediency rather than by a program of free inquiry.

While the state of the art seems to be such that few important generalizations can be made at present, as time goes on more and more consolidation of results from the specific solution type of approach should yield principles of wide application — as has been true in other, more mature areas of knowledge. This gives hope to an otherwise depressing situation, for with respect to the special problem of concern to this conference I believe that it would not require much more than the fingers of both hands to count the research reports which have systematically and scientifically examined the special problems of equipment design for manual function in cold climates.

In the light of these considerations, it will not be my main purpose in this paper to attempt to suggest broad equipment design principles or to review extensively the few reports I have seen. It will be the main purpose of this presentation to outline and discuss what appear to be some of the important problems of equipment design in relation to hand functioning in the cold and to illustrate them with pertinent experimental results where feasible. This will be followed by a review of some of the research we have been doing on these problems in the Biotechnology Laboratory at UCLA. At the outset, I must admit to being severely limited with respect to personal qualifications for expertness on this topic in the form of a repertory of experience with equipment in cold climates. I've never lived in such a climate with the exception of part of one mild winter spent in this local area. Accordingly, if some of my examples of practical cases appear naive, they are.

What are some of the aims of optimum equipment design from the standpoint of function with the user? Allowing that optimum design is generally a compromise among the influences of many variables in a situation, it is commonly agreed that the aims fall into three general areas: (1) To achieve maximum comfort and ease of use; (2) To achieve maximum safety; (3) To minimize the training necessary in

order to use successfully. These categories are, of course, mutually interdependent. Let us examine each of these aims in turn with respect to the design of equipment for use in the cold.

For maximum comfort and ease of use, one special problem of the cold is that, in order to achieve thermal comfort, the man may have to wear heavy protective clothing over his body and mittens or gloves on his hands. Immediately, under these conditions, the effects of equipment design on manual function are apparent. Equipment that under normal thermal conditions would meet the requirements for optimum design may now become virtually useless or require additional training of the user. The most obvious problems are anthropometric ones. The gloved hand is larger; it cannot get into as small a space as when bare — such as the trigger guard on a gun, or between the knobs on a “miniaturized” piece of electronic equipment. Arm movement angles may be restricted by bunching of material at the joints when acute angles are attempted, etc. Population data on hand and arm measurements, as for example that of Hertzberg and Daniels or Newman and White (1, 2) do not offer the equipment designer much help in allowing for such factors. Neither do the usual sources of data used by designers which specifically show the influences of hand dimensions on the design of knobs, levers, drawer pulls, etc. (3, p. 310). A recent report by Dempster (4) (which promises to become a classic in the field because of its relative completeness in dealing with dynamic aspects of the body and limbs) does not indicate how one could apply the data cited to make an equipment design decision which would allow for protective clothing in severe environments. The designer is left on his own to make a “good guess” and it is more than likely that he may not even have been told that his design may have to be operated by a man wearing heavy handwear in an environment of  $-30^{\circ}\text{F}$ . Many government procurement contracts now have human engineering specifications in them. Specification of operational environments is necessary to achieve this as well as the other aims of optimum design. Environmental specification may be enough in the early paper-and-pencil stage, where an informed guess can mean the difference between success and failure and at least is better than nothing.

Besides the anthropometric problems, there are more subtle ones, such as loss of or distortion to the tactile senses of the fingers. Mr. Mills has already discussed this particular problem and more will be said about it later. Suffice it to say, the loss of capacity for making decisions about the state of equipment is one of the more serious effects of handcoverings even when known optimal equipment designs are used. Hunt and Craig (5) studied 31 differently shaped knobs under rather simple test conditions which required their subjects properly to identify the knobs while blindfolded. The results indicated that even wearing light flying gloves increased the confusion errors among the knobs such that of a total of 669 errors made in 13,560

judgments, 61% were made by the subjects while wearing gloves and 39% with the bare hand. The tests took place at ordinary room temperatures, so that any complications from direct effects of a cold environment on the thermal balance of the body or the use of heavier gloves for thermal protection may be presumed to have increased the number of errors.

In another type of experiment where subjects were required to make angular settings of knobs, Bradley and Stump (6) found that none of three different weights of gloves had any measurable effect on either reach times or turning times as compared with the bare hand. Their task appears to have been dominated by proprioceptive rather than tactile cues. A comparison of the task requirements in these two experiments indicates that, so far as optimum equipment design is concerned, a given task must be carefully analyzed for the requirements it places on the capacities of the human component. Optimum design of equipment for a particular use does not, in general, mean that the equipment will meet optimum design requirements for another use even when the uses are superficially similar. In the examples cited, design requirements for knobs which are to be located under blind reaching conditions, without confusion with other knobs, are somewhat different than those for knobs which must be turned accurately — though apparently both functions may be served without conflict. Task analysis as well as specification of the environment in which the task will be done is another essential requirement for achieving the aims of optimum design.

With respect to the aim of safety, much has been and will be written. A special safety problem of manual function in cold environments is that of equipment which must be handled at extremely low temperatures. There is danger of freezing the skin of the hand at points of contact; there is also the danger of rapidly cooling the entire hand. Daniels (7) investigated one possible solution to this particular problem, namely, that of covering exposed metal with a material of low thermal conductivity. At  $-20^{\circ}\text{F.}$ , three subjects exposed their hand to air, held samples of aluminum and steel pipe covered with "ensolite" (expanded polyvinyl chloride) foam plastic, and as an additional condition held a bare metal pipe. The important conclusion of this experiment was that ensolite decreased the rate of cooling by an amount sufficient to justify the practical suggestion that a permanent low conductivity covering be applied to exposed metal parts that require handling. This method, in many instances, may be more feasible than protection by insulating the hand. This is particularly true where hand dexterity is of major importance.

In general, it seems tenable to assume that problems of safety arise with special contingencies that appear in the course of an operational situation. Again, task analysis in relation to the probability of appearance of these contingencies and to the capabilities of the man-equipment combination for handling them appears to be a neces-

sary approach for successfully designing equipment for use in the cold.

The third aim, that of minimizing the amount of training necessary for performance of the task, is of unique importance. In my opinion, this criterion is inherently the best single indicator of the effects of equipment variables on manual function. Ideally, with this criterion we would expect that optimum designs would be defined when very small amounts of practice are required to perform a given task. Perhaps this requires some explanation.

The goals of a task are usually set up in terms of some function which it is desired to accomplish, for example: to pitch a tent; light a stove; open a can. In addition to the economies of time effected, equipment improvements that lessen the training required to accomplish the goals of a task tend to reduce the level of ability required, making it possible to utilize individuals previously unsuited for the task. This means that a given task for which a level of adequate performance can be defined can be used to rank order individuals doing the task. The rank ordering for this purpose is in terms of the number of trials it takes to achieve the criterion of adequate performance. In very difficult tasks, such as flying presently designed jet airplanes, a large amount of practice is necessary and many individuals will never qualify. For simpler tasks such as driving an automobile, relatively few trials may be required for the majority of individuals and nearly everybody may eventually succeed. Simplification of the task through equipment design in relation to human capacities is usually accomplished at the expense of complicating the equipment, as witness the modern can opener as compared to opening a can with a cold chisel — or the electric automobile starter as compared with a crank. Complication does not necessarily lower the reliability of the equipment. As in many cases the development of more complications means that a better understanding of important design variables has occurred. Complication obviously places a larger burden on the equipment designer, however, and he may be tempted to require users to adapt to design shortcomings that he could avoid. Specification of the maximum allowable amount of training required and the general level of ability of the group of people for whom a given piece of equipment is designed is, in my opinion, of equal importance to the specification of operational and environmental conditions of use. For the designer, the ultimate goal should probably be to design the equipment in relation to the task so that little or no training is required for anyone.

In connection with equipment design for manual function in cold environments, a particular training problem arises when an individual dons protective handcoverings. The loss of hand dexterity as a function of the finger manipulation requirements and the degree of hand protection required is well known. It has been proposed that decrements in manual performance, which can be traced to wearing of handcoverings, may be overcome through extended practice. Experi-

ments conducted by members of the Psychology Branch of the Environmental Protection Division lend a certain amount of support to this proposal. For example, Teichner, Kobrick, and Dusek (8) have reported that the combined scores from a test battery consisting of the Craik Screw Test, the Minnesota Rate of Manipulation Test and the Block-Packing Test for six subjects improved slightly over 200 percent with an arctic mitten and liner, 50 percent with a cold-wet assembly, and 20 percent with a liner alone, after 25 trials. From the viewpoint of this discussion, it is interesting to note that despite these relative improvements, the rank of each of the glove conditions with respect to the bare hand remained the same throughout the trials. It may be argued that additional practice might have brought performance to the point where it was unimpaired for even the arctic mitten. The following questions arise. Under experimental conditions such as those cited, aren't the subjects simply learning a special skill for performing the specific task assigned with handcoverings on? Would the abilities required for this skill tend to be a selective factor so that some subjects would never reach an arbitrarily defined level of proficiency? It seems to me that the answer is "yes" to both of these questions. In the same report the authors point out that so far as manual dexterity is concerned, there is no single dexterity but rather, there are many specific dexterities (8, p. 1). The apparent specificity of manual skills is well known and suggests that there is no assurance that a skill learned with handcoverings on will lessen impairment when other tasks are attempted with handcoverings. The degree to which this might be expected to be true would, of course, vary with the complexity of the skill. Taking this into account, I would like to submit that, in addition to the specificity of dexterities, there is a specificity of proficiency level for a given task and that the overall objective of equipment design is to permit achievement of this level by as many individuals as possible within the framework of the aims we have been discussing.

Figure 1 schematizes the rather elementary but important concept of performance proficiencies. It may be noted that if a given individual ordinarily performs at the level of minimum competent performance for a given task, he may perform at the emergency or disaster level with protective handcoverings on. This may continue to be true even

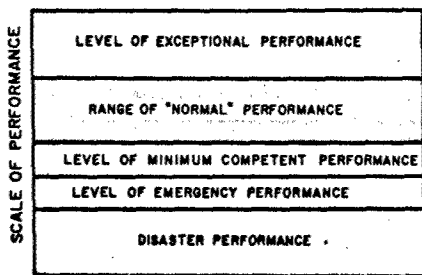


FIGURE 1. Performance proficiencies.

after some improvement with practice. I cannot conceive, for example, of a concert pianist performing at a competent level with a cold-wet ensemble even after extended practice, though the obvious rejoinder may be: "But who would want to play a piano with gloves on anyway?" Be this as it may, the question of how far one can support the position that, where equipment design fails, practice by the human will make up the difference is merely academic. Few people today would argue against the notion that the direction of progress is the direction of adapting equipment to the capabilities of men rather than adapting men to the capabilities of equipment. It is a matter of the sophistication of a given equipment design technology and, for the equipment designer, the adaptive abilities of man should probably be considered as a last ditch defense against technical ignorance.

Where should leadership in the field of equipment design for manual function in cold climates look for progress? I would be presumptuous indeed if I pretended to have a pat answer. With a program of activity the size of that available to the armed services progress, as in the past, will probably come from several directions concurrently. In terms of immediate goals, however, it appears to me that there is some choice of direction and that this choice may be of considerable importance to long term progress. As an example, suppose that a given essential task may be done proficiently in "comfortable" environments without special protection but that performance is impaired when it is necessary to do the task in cold climates. On the assumption that practice is not the answer, two choices and the possibility of a compromise are open from the standpoint of equipment design: (1) The task may be redesigned in terms of the equipment associated with it. For example, the filler cap in a camp stove might be redesigned so that the cap is a funnel of sufficient diameter to be easily grasped and turned by a man wearing arctic mittens. (2) The mode of protection from the environment may be improved or changed so that the task can be done proficiently. Here, the possibility of providing warm microclimates for the body through the use of special purpose clothing so that light handcoverings could be worn or handcoverings could be removed altogether is apparent.<sup>1</sup>

The probability of facing the alternative design choices proposed is high for many tasks which are necessary for operations in cold climates. The first choice requires specific attention to the equipment involved in a particular task and as such will be likely to yield an

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<sup>1</sup> I recently discussed the possibility of utilizing such special purpose clothing with Mr. H. A. Mauch, Chief, Environmental Section, Physiology Branch, of the Aero Medical Laboratory, WADC. He has developed a successful air-ventilated suit for protecting pilots from high cockpit temperatures (9) and I believed that it might be possible to utilize the heat from the exhaust gases or radiator water of vehicles for providing comfortable microenvironments for such personnel as mechanics in cold climates. He thought this approach might be feasible, but felt that an electrically-heated suit would be better since there would be less heat loss during transmission from the source. He further suggested that with modern advances in wiring, it would probably be feasible to develop an efficient and reliable electrically-heated suit. Such a solution would probably not have the generality of application that would accrue to a basic improvement in handcoverings.

*ad hoc* solution. When the task is important and performed frequently, this may well be the approach to use — especially when the new equipment design may simplify the task for temperate as well as for cold climates. The second choice opens the possibility of a more general solution since its purpose is to remove the performance impairment effect of the environment so that the task can be carried out under circumstances more comparable to those in a temperate climate. At present this is a relative generality, for solutions which require changes in the man's environment are likely to confine him to a limited area of operations so that he will be near power for his heat source. It is possible that the highest degree of generality may be associated with basic improvements in handcoverings. In the light of the present status of handcovering technology and certain theoretical limits for hand protection by insulation, based on heat exchange considerations (10), even this solution will probably be no panacea. Recognizing that the latter approach has a large potential for development despite its limitations — especially when coupled with progress to be made by the other choices which I have described — I would like to turn now to a discussion of some of the research on the design variables of handcovering which we have undertaken in our Biotechnology Laboratory in the Department of Engineering at UCLA. Most of the experiments I shall refer to have been compiled into a detailed report for the Army Quartermaster (12).

What is it about a handcovering that interferes with function and, specifically, what function or functions of the bare hand are affected? In order to assess this question, we have proposed the block-diagram conceptual model for information flow in a hand-glove-object system shown in Figure 2. It is a "closed loop" system which in many respects is analogous to the models used by engineers for describing the control circuits for servo-mechanisms. The human portion of the system is represented in the diagram by three major units: a measuring unit, a correlating unit, and an output unit. The measuring or sensing por-

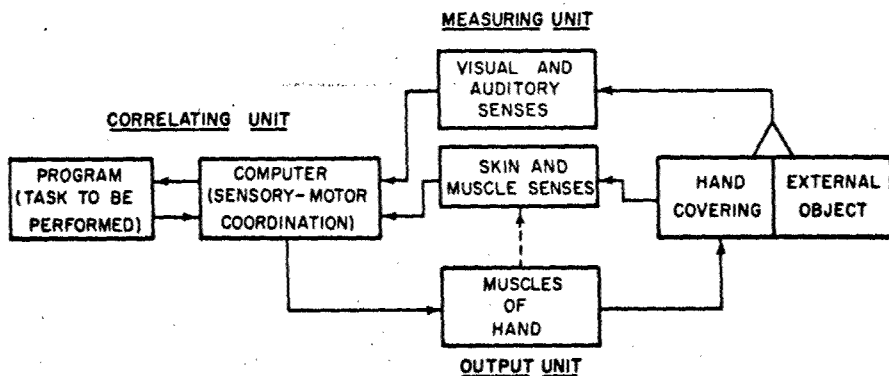


FIGURE 2. Information flow for a hand-glove-object system.

tion serves to channel information about hand-glove-object interactions to the correlating unit where the information is compared to criteria for a program of performance. Outputs from the correlating unit control the muscles, which in turn present additional information to the correlating unit by proprioception and bring about changes in the condition of the external object by means of an energy transfer. The dotted line between the muscles and muscle sense indicates a feedback loop for proprioceptive information. In this system, the inclusion of a handcovering between the external object and the hand appears to have two important effects: (1) Information to the cutaneous senses may be distorted and/or lost. (2) The forces applied to external objects act through a configuration of materials having properties different from those of the bare hand.

If this crude model is a reasonably correct approximation to the system, we can reason that since kinesthesia is inherent in the muscles and joints, information about prehension force, movement, and position is present and valid with respect to the hand-glove interaction; however, not necessarily correct with respect to the glove-object interaction. Because reaching and positioning movements depend more on information from the muscles and joints and on gross visual cues than on glove-object interactions, it may be expected that such movements will tend to be relatively unaffected by handcoverings. This indeed seemed to be the case for the knob setting experiment of Bradley and Stump (6) cited earlier. This proposal apparently leaves the major portion of the effects of handcoverings to the skin senses. These senses are capable of great sensitivity to pressure gradients and a variety of spatial relations and patterns may be perceived. To the extent that these sensations are reliable indicators of the glove object interactions, they can be utilized to supply (medium) glove assemblies. The three tests used were: the Minnesota Rate of Manipulation Turning Test which requires that a series of cylindrical blocks be picked up on one hand, turned over and replaced in a hole with the other hand; the Craik Screw Test which requires the subject to unscrew a screw next to a vacant hole, insert it in the vacant hole, screw it in, then repeat for a series of screws; and the Plug Insertion Test which requires the subject to grasp a plug inserted in a vertical disk, remove it, place the plug on a mat next to the disk, pick it up, return it. A series of plugs of different sizes were used.

The results indicated that for all three tests there were no statistically significant differences between the intact glove assembly and the ends-only conditions. Large statistically significant differences did appear between each of these conditions and the bare hands. The "ends out" condition showed small but statistically reliable differences as compared to bare hand on the Minnesota and Craik Screw tests, but no difference on the Plug Insertion Test. The restraint variable was significantly different from the bare hands for all three tests. Its effect lay about midway between the level of bare hand per-

formance and performance with the intact glove assembly and the ends-only assembly. When it is considered that the restriction provided by this device was appreciably greater than is normally found for glove assemblies, the effect was surprisingly small. From these observations and some others, it was concluded that the major source of impairment for skills of the kind needed for the tests was localized at the ends of the glove fingers. On the basis of these findings, Mr. Sheridan carried out an additional series of tests to determine the effects of hand function of various types and appropriate corrections to the correlating unit. Mr. Mills and Dr. Dusek have already discussed the effects on loss of tactile sensitivity from the cold. In the case of handcoverings, however, loss of tactile sensitivity *per se* is probably not the problem unless cold hands complicate the picture. Rather, the physical properties of the handcovering materials appear to limit the precision of information available to the skin senses for correcting "errors" in performance. The "errors" themselves appear to be partly a function of the properties of the handcovering materials in relation to the object, such as thickness, bulk, frictional characteristics, etc., increasing the complexity of the problem further.

In order to investigate experimentally the nature of the relationships in the hand-glove-object system, it was believed necessary to simplify the problem somewhat, if possible, by determining the general boundaries of the site on the hands at which the interactions take place. This task was undertaken in 1954 by Mr. Thomas B. Sheridan as part of his work toward an MS in engineering. Four experimental handgear assemblies were constructed as shown in Figure 3. The assemblies consisted of an intact glove line assembly, a similar assembly with the ends of the fingers cut off at the distal phalangeal joint, an "ends only" assembly in which the cut-off ends of the second assembly were secured to a light cotton glove, and a "restraint" assembly consisting of steel springs attached to a holder which could be secured to the wrist. Figure 4 shows how the device was worn. It will be noted that the fingers were free so that force and sensation transfer were normal. Eight adult male volunteer subjects from the engineering staff and student body participated in the experiment. A criterion for selection was that the hands of each subject satisfactorily fit the size 4 locations of material on the finger tips. Figure 5 shows the materials that were used. Various configurations of  $\frac{1}{8}$  inch sponge rubber,  $\frac{1}{4}$  inch sponge rubber and  $\frac{1}{8}$  inch cork were inserted in tips cut from rubber balloons in such a way that different portions of the fingertips were covered. To change the frictional coefficient, a piece of adhesive tape was placed on the outside of one of the balloon tips and on the inside of the other in order to control thickness.

Figure 6 shows how the materials were mounted on the fingers. In a different experiment it had been shown that for the manipulation tests used only the thumb and first two fingers were of importance. With certain modifications in procedure, the same three tests as be-

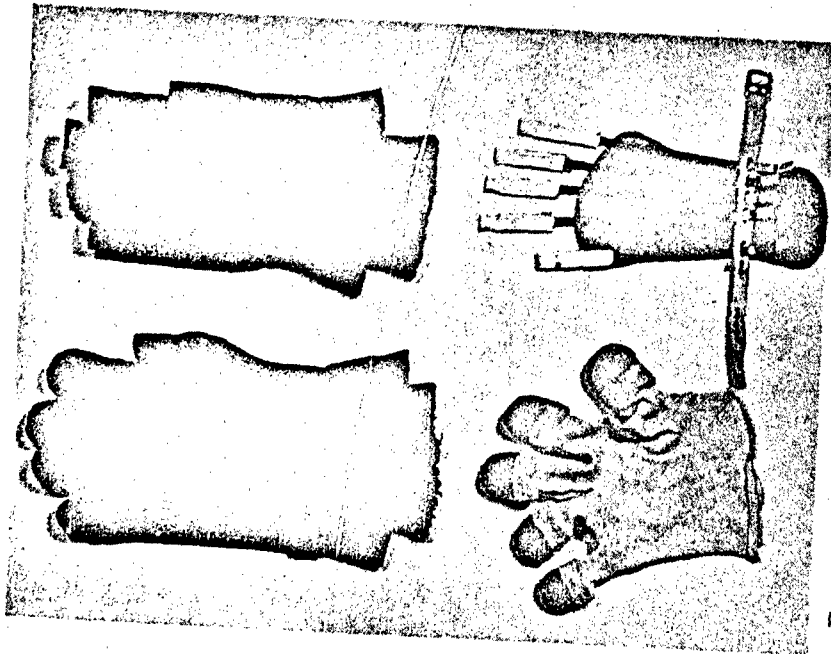


FIGURE 3. Handgear assemblies used for determining site of design variables affecting hand dexterity.

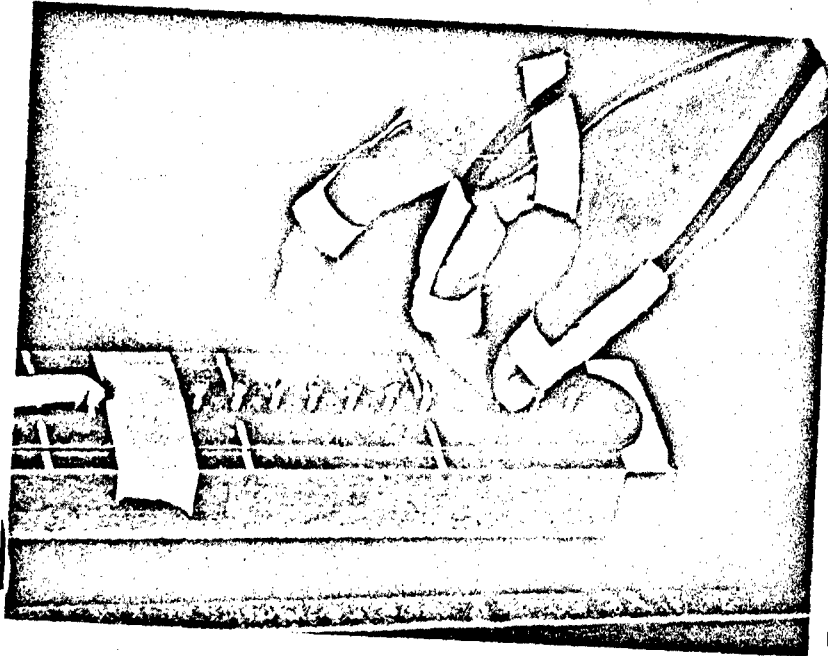


FIGURE 4. Application of restraint assembly to hand.

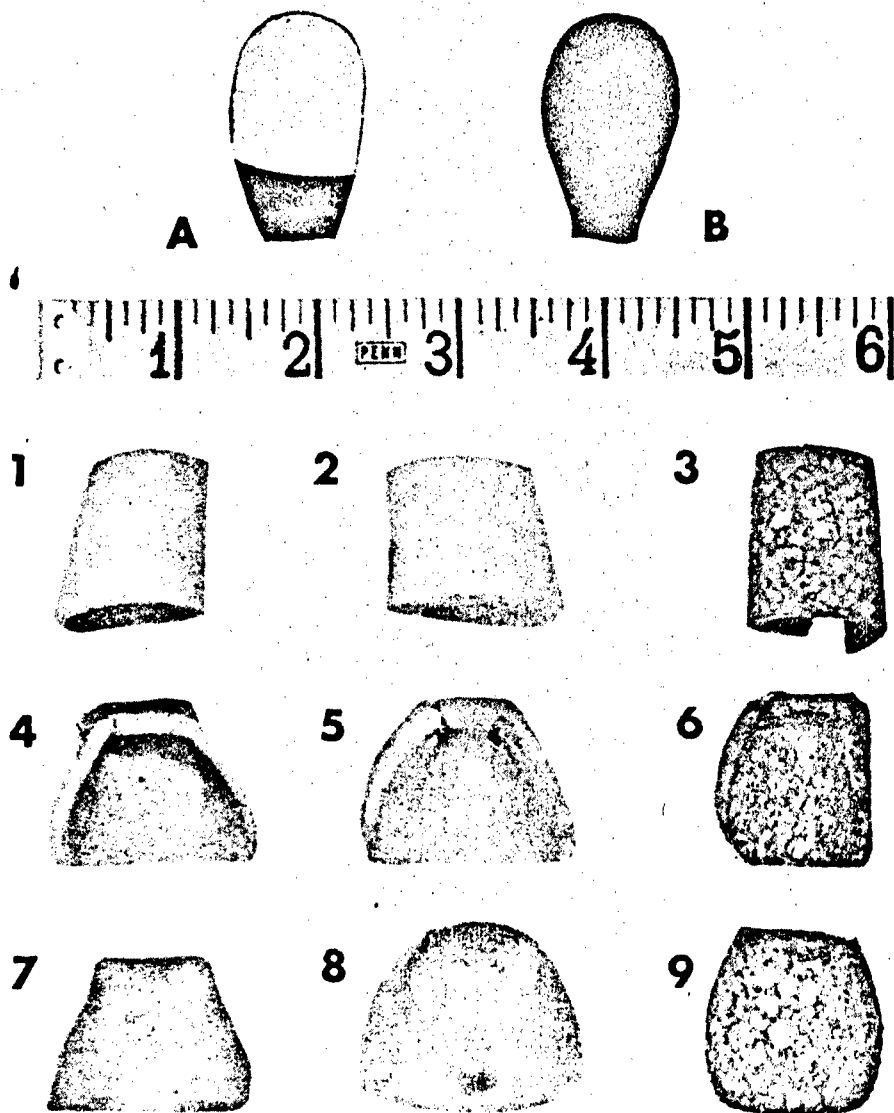


FIGURE 5. Glove materials, covering and lining. Coverings: A—Tape contact surface; B—Rubber contact surface. Lining materials: 1—Sponge rubber,  $\frac{1}{8}$  inch thick, palmar surface covered; 2—Sponge rubber,  $\frac{1}{4}$  inch thick, palmar surface covered; 3—Cork, palmar surface covered; 4—Sponge rubber,  $\frac{1}{8}$  inch thick, tip surface covered; 5—Sponge rubber,  $\frac{1}{4}$  inch thick, tip surface covered; 6—Cork, tip surface covered; 7—Sponge rubber,  $\frac{1}{8}$  inch thick, tip and palmar surfaces covered; 8—Sponge rubber,  $\frac{1}{4}$  inch thick, tip and palmar surfaces covered; 9—Cork, tip and palmar surfaces covered.

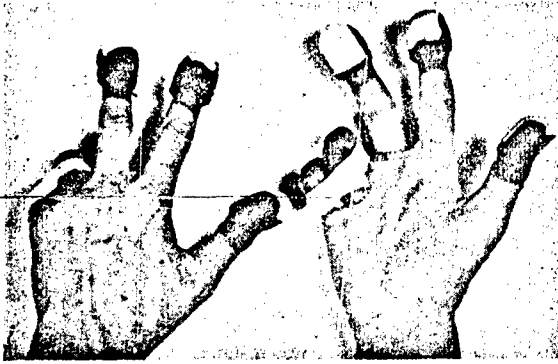


FIGURE 6. Experimental configuration on subject for determining effects of type of material, location of materials, and surface contact friction on manipulation.

fore were used. The tests were administered to four subjects. The results clearly indicated that lining materials, location on the finger, and surface frictional characteristics all had important effects on the skills measured by the tests in the experiment. These effects interacted with each other and with the tasks but, in general, it could be concluded that stiff handcovering materials probably impair performance more than flexible materials, that low coefficients of friction at the contact surface impair performance, and that the covering of the palmar and tip surfaces of the fingers has a greater effect than covering the tip surface or palmar surface alone. For different tasks the relative importance of the portion of the finger covered may be different.

In an experiment to determine what portions of movement might be affected by gloves, Mr. Dimitris Chorafas collected motion picture data and made a micromotion analysis of twelve subjects taking the Minnesota Rate of Manipulation Placing Test and the Plug Insertion Test as part of his work for an MS in engineering. Under the different conditions of the tests, the subjects were bare handed, wore latex surgeon's gloves, and wore a trigger finger mitten and liner assembly. The results of the study indicate that when compared to bare hand performance, the glove conditions did not produce any statistically reliable effect on the travel time elements of motions (i.e., reaching for or moving objects from one location to another). Both types of glove reliably affected motion elements involving manipulation. The results of both Sheridan's and Chorafas' experiments conform to predictions from the hand-glove-object model which has been outlined.

In addition to these experiments, we have been investigating the possibility that other measures than time of performance or errors in performance may yield fruitful information about the effect of equipment variables on hand function. To this end, Mr. Ben Chapman, a student aide in our laboratory, constructed a small cylinder into which various weights could be inserted and which would measure prehension force when the cylinder was picked up. In the experimental setup shown in Figure 7, this device was used to obtain data on pre-

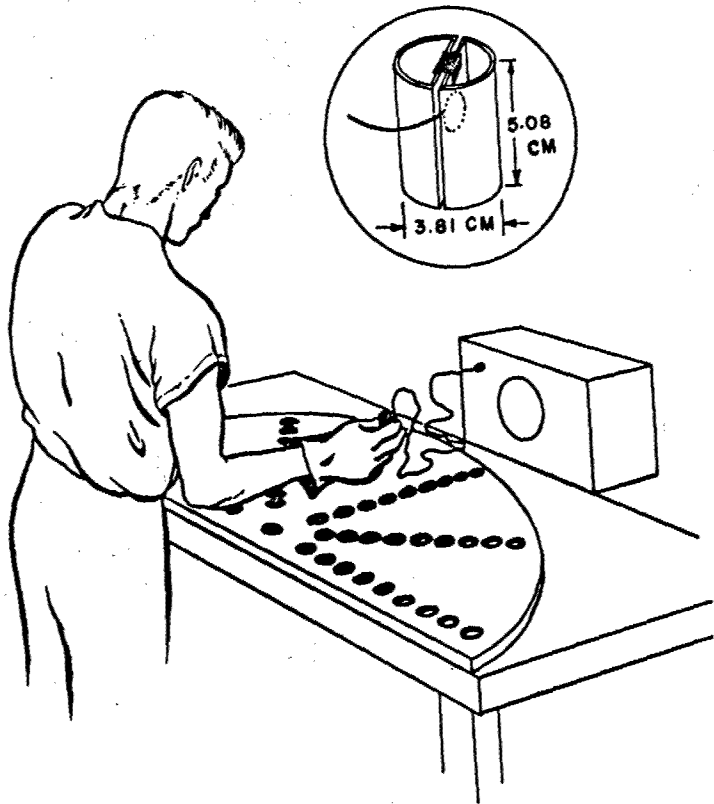


FIGURE 7. Experimental setup for prehension force experiment.

prehension force from six engineering students as a function of the weights, direction and distance of movement, and condition of hand-covering. Bare hand prehension forces were compared with hand-covering conditions consisting of surgeon's latex gloves and the same intact glove assembly which Mr. Sheridan used. On the command of the experimenter, subjects moved the device from a center location to a designated hole and then returned it. The criterion measure was peak force at the return part of the cycle. The results indicate that peak prehension force is reliably affected by weight, condition of handcovering, and the distance which the object is moved. In addition, the condition of handcovering interacted with the weight variable. Since weights of less than one pound were used in this experiment, it is possible that the interaction may be at least partly attributed to differences in the weights of the gloves relative to the weight of the object. It is of special interest to note in this experiment that, on the average, approximately twice as much prehension force was applied when glove-liner assembly was worn as when the bare hand was used. The data suggest that increased prehension force may be the *modus operandi* for hand fatigue which is known to mani-

fest itself in impaired performance as indicated by time measure (8).

Within the past few months a new prehension force measuring device has been constructed and tested by Mr. J. R. Zweizig, a graduate student and member of our Engineering Manual Function Project. This device is shown in Figure 8. Figure 9 shows it mounted on a subject. It has the advantage of being independent of the object manipulated and it does not interfere with hand movements. It is not suitable

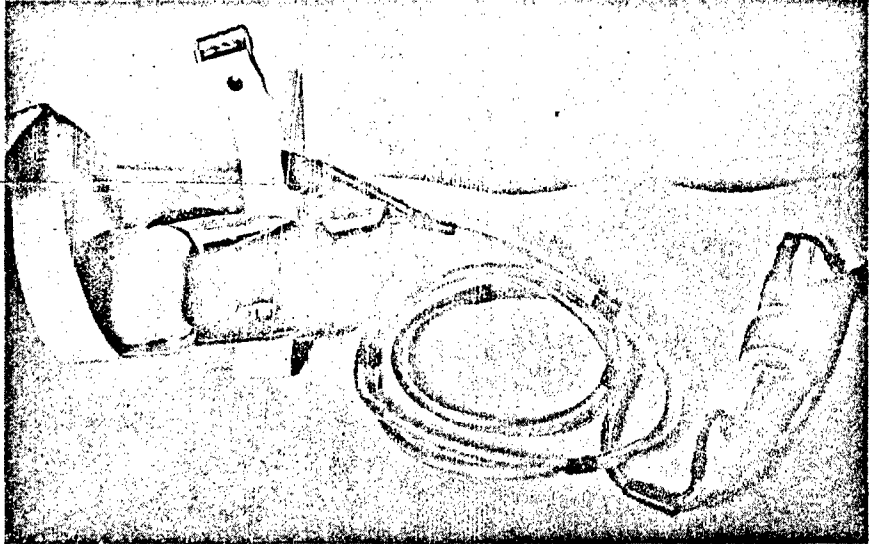


FIGURE 8. (Above) Muscle force transducer for measuring prehension force.

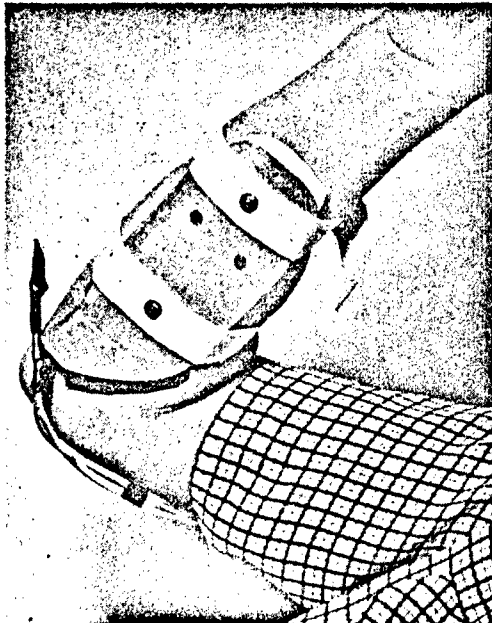


FIGURE 9. Muscle force transducer in place on subject.

for use under all task conditions, but for light tasks where grasping and positioning are the dominant motion elements it seems to work very well. We have been making some methodological studies of data recently obtained on six subjects in an experiment that was similar to the prehension force experiment I just described except that no gloves were used and the weights ranged from one to four pounds. With the aid of an analog computer, we have been able to measure the integral of force as well as instantaneous force and time. A typical record is shown in Figure 10. From the data we have obtained, it appears that both with peak force and the integral of force we are making measurements that relate to variables in the task different from those measured by time alone. On the basis of our results so far, we believe that a particularly useful measure of certain aspects of skill in relation to equipment variables may be some function of force squared, but we don't yet know what function will be best.

In summarizing this rather speculative discussion I would like to emphasize again that the experimental evidence developed so far indicates that the relations between equipment design variables and manual performance in cold climates are extremely complex. Science performs miracles slowly, but usually thoroughly. I haven't the slightest doubt but that the next few years will see some really major breakthroughs on the problems of protection and functioning of the hands in cold climates, perhaps as a result of new direction given by this conference. The primitive state of our present knowledge, as suggested by the fact that we are still trying to define the problems and

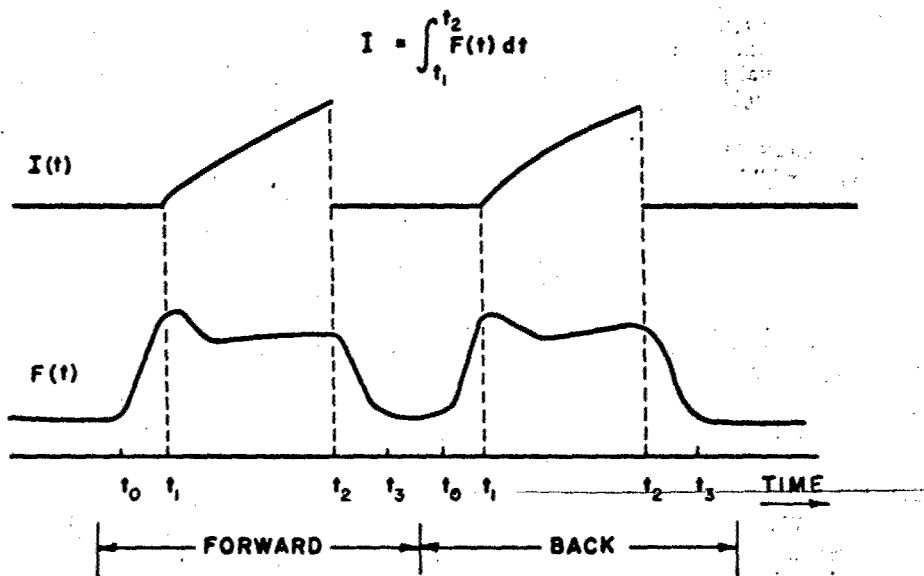


FIGURE 10. Typical record of prehension force with muscle force transducer.

variables of importance, does not require apology. It is, rather, an invitation to challenging opportunities for participation in progress.

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CHAIRMAN TEICHNER: The next paper will be the "Kinesiological Parameters of the Hand," by M. Gladys Scott.

## KINESIOLOGICAL PARAMETERS OF THE HAND

M. GLADYS SCOTT

Functionally, or kinesiologicaly, few, if any, parts of the human body have been studied less than the hand, or at least presented more sparingly in the literature. Anatomically, in terms of bones, muscles, and articulations, it is as well understood as any body segment. Physiologically, its performance is similar to that of the rest of the body mechanism for movement and coordination, touch, and kinesthesia. But, the specific movements and peculiarities of the hand function have concerned few physiologists:

For the psychologist, the hand is often the tool of overt reaction, and to study this, tapping, tracing, and other manipulatory and dis-